PERSPECTIVES FROM SPAC

International Space Year

ISY

NASA Classroom Information and Activities

This booklet contains the information and classroom activities included on the backs of the 8-poster series, "Perspectives From Space." NASA distributed the series in celebration of International Space Year, 1992. Information on NASA Educational programs and resources is included on the inside back cover.

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PERSPECTIVES FROM SPACE

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1a Global Ecology

During the last few centuries, human kind has entered into a new relationship with the global environment. We now rival natural forces in our influence on the makeup of our planet. We alter the face of the Earth by clearing forests, building cities, and converting wild lands to agriculture. During the past century, industrial production has risen by a factor of more than 100, and the use of energy by a factor of about 80. We have changed the composition of the Earth's atmosphere through the use of fossil fuels, the expansion of agriculture, and the production and release of industrial chemical compounds. Almost without recognizing it, we have embarked on an enormous, unplanned, planetary experiment that poses unprecedented challenges to human wisdom, foresight, and scientific capability. We are just beginning to understand the myriad forces that interact within the Earth system, creating and sustaining life as we know it.

Earth's Interacting Subsystems

Geosphere: The physical elements of the Earth's surface, crust, and interior. Processes in the geosphere include continental drift, volcanic eruptions, and earthquakes.

Atmosphere: The thin layer of gas, or *air*, that surrounds the Earth. Processes in the atmosphere include winds, weather, and the exchange of gases with living organisms.

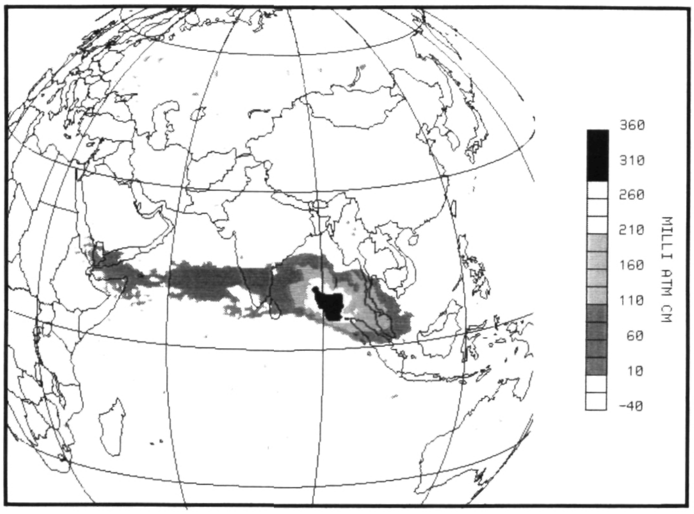
Hydrosphere: The water and ice on or near the surface of the Earth. Includes water vapor in clouds; ice caps and glaciers; and water in the oceans, rivers, lakes, and aquifers. Processes in the hydrosphere include the flow of rivers, evaporation, and rain.

Biosphere: The wealth and diversity of living organisms on the Earth. Processes in the biosphere include life and death, evolution, and extinction.

Understanding the Earth System

Every individual part of the Earth, from the tiniest living organism to the vast expanse of the oceans, ultimately interacts with every other part. Together, these parts and their interactions form the complex web that we call the *global ecology*. To achieve a comprehensive understanding of the Earth, we must study both the individual parts and the interactions among them.

We can think of the Earth as comprised of four, major subsystems: the *geosphere, atmosphere, hydrosphere,* and *biosphere* ("spheres" because each extends over the entire Earth). By studying each subsystem—or small parts of the subsystems—individually, we learn important details of the global ecology. By studying the subsystems and their interactions together, we develop a global understanding of the Earth.



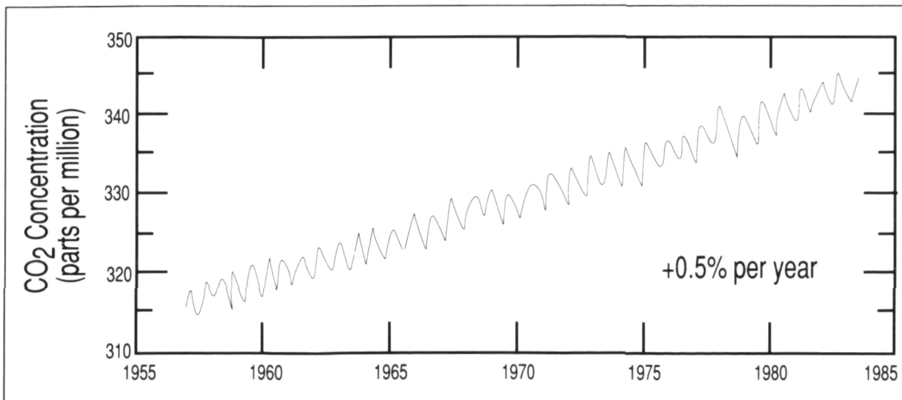
Upper Atmosphere Research Satellite (UARS) image, showing the volcanic plume from the eruption of Mt. Pinatubo (Philippines, 1991) stretching around the world.

As an example, consider the eruption of a volcano. The eruption is a process of the geosphere, releasing ashes and gases from the Earth's interior into the atmosphere. In the atmosphere, the volcanic emissions tend to cool the Earth, changing the climate and altering rainfall patterns. Since rainfall is water, the volcano has affected the hydrosphere. Finally, these short-term changes in the atmosphere and hydrosphere affect the biosphere, and living organisms are forced to adapt or die.

Global Change

Since the Earth first formed, some 4.6 billion years ago, it has seen immense natural change. Whole continents drift across the globe, and mountains rise up from ocean floors. The global climate varies greatly, with some past periods much warmer than today, and others immersed in ice ages. Even the composition of the atmosphere changes, through outgassing by volcanos and the respiration of living organisms. Indeed, for most of Earth's history, the air would have been unbreathable for humans.

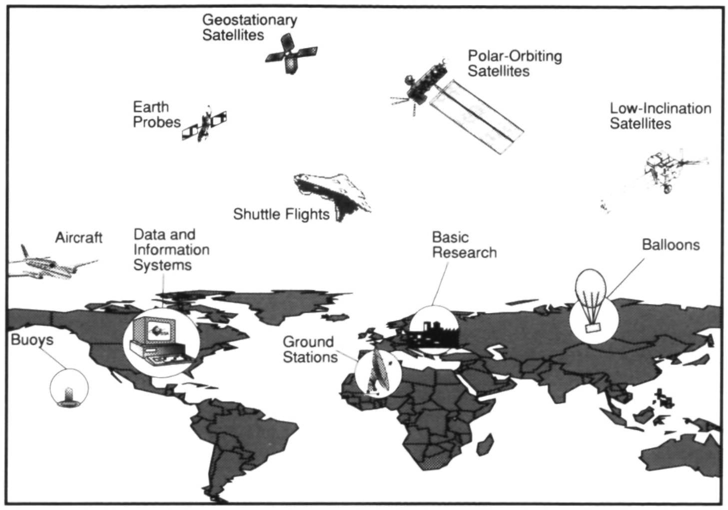
Natural change usually occurs slowly, allowing the global ecology ample time to adapt. In contrast, human activity today is causing changes so rapidly that we can measure significant ecological effects in the span of a single human lifetime. What will the consequences be? Increased awareness of human dependence and impact upon the environment has made global change one of the most pressing research issues of our time.



CO_2 Concentration

The astonishing rate at which human activity can affect the environment is illustrated by the rising concentration of carbon dioxide (CO_2) in our atmosphere. Generated primarily by the use of fossil fuels like oil and coal, and by the cutting or burning of forests, CO_2 concentration has risen nearly 15% in the last 30 years, and has doubled since the dawn of the industrial age. The yearly "wiggles" show that CO_2 concentration varies with the seasons.

1b Mission to Planet Earth



Components of Mission to Planet Earth.

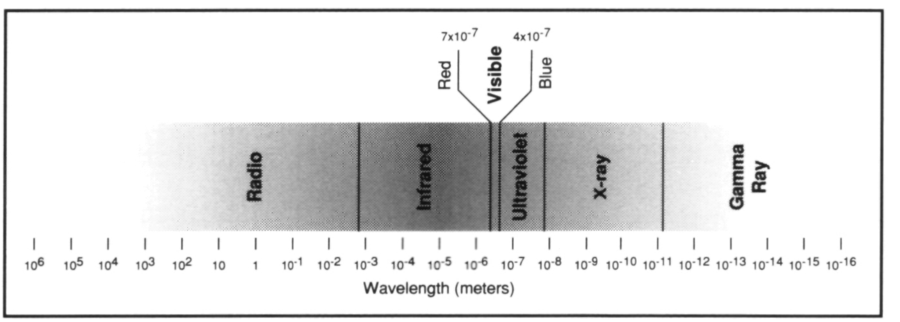
Mission to Planet Earth is the name given to an intensive, international scientific effort to better understand our planet. The study involves a three-tiered approach. First, we need the basic data collected through measurements made on the ground, from aircraft and balloons, and by *remote sensing* from space. Next, the enormous quantities of raw data must be sifted and shaped into useful *data products.* Finally, researchers must interpret the data, a process aided by *Earth system modeling*—the use of computers to model and predict the processes that govern the Earth system. Only through this comprehensive approach can we accurately detect changes in the Earth's subsystems and differentiate human-induced changes (e.g., pollution) from natural processes.

Remote Sensing From Space

Remarkably, many measurements of the Earth are best made from space. In fact, *remote sensing* of the Earth's environment by *satellites* in space ("remote" because the satellites are not on the surface of the Earth) provides the only truly global perspective. Different *orbits* allow satellites to study different phenomena. Some satellites orbit at *low inclinations*—passing over the Earth near the equator. Others are in *polar orbits*, viewing a north-south swath of the Earth on each orbit. Still others are in *geostationary orbits,* where they view the same portion of the Earth at all times.

Remote sensing satellites study the Earth by sensing and recording various forms of light, or *electromagnetic radiation.* For example, infrared observations help us monitor large fires on the Earth's surface, like those set to convert the Amazon rainforest into farmland, or wildfires ignited by lightning in Yellowstone Park (illustration on poster front).

Passive remote sensing instruments simply observe light reflected or emitted from the Earth (or elsewhere). Examples of passive measurements include the infrared images of fires, and measurements of the reflectance of light that reveals information about the extent of vegetation (see illustration on poster front). *Active* instruments send pulses of energy (using *lasers* or *radar*) toward the Earth and measure the timing and shape of the returning pulses. Active measurements can reveal information like the *topography* (roughness) of the Earth's surface, cloud details, the shapes of waves on the ocean surface, or wind speed (see illustration on front).



The electromagnetic spectrum. The visible light that our eyes can see is just a tiny part of the complete spectrum of light. Light is also called electromagnetic radiation, because light carries electric and magnetic fields through space.

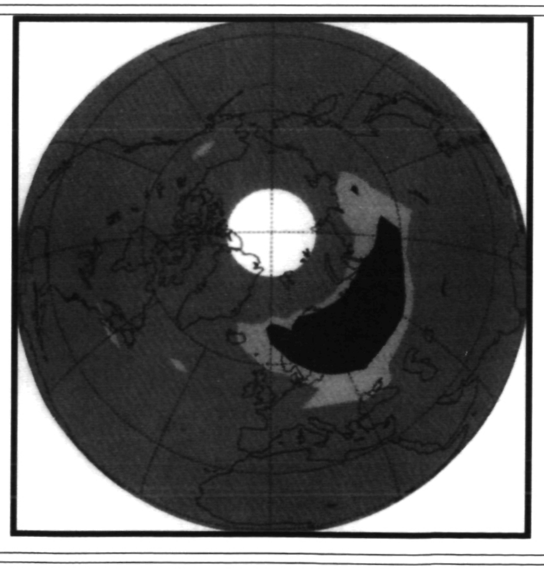
Data Products

Satellites transmit collected data, via radio signals, to *ground stations,* and then on to research centers around the world. The sheer quantity of data is mind-boggling; a single satellite can return enough raw information to fill a thousand books in a day. One of the great challenges in Earth science is the development of data systems to help researchers extract the most important information. Successful data systems can turn millions of *bits* of raw data into colorful and informative data products, like those shown on the front of the poster.

The Loss of Ozone

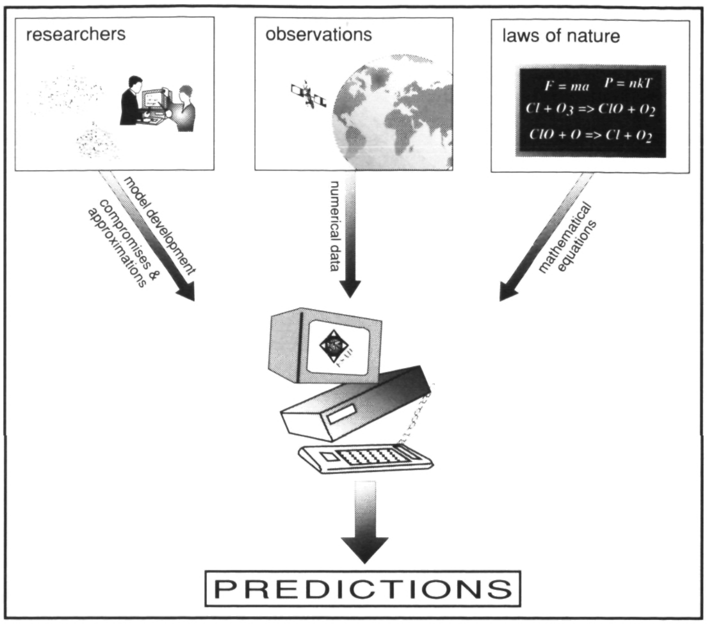
Ozone is a molecule made up of three oxygen atoms (O_3; the oxygen we breathe is O_2), found high in the Earth's atmosphere. The presence of ozone is critical to life on Earth, since it absorbs harmful ultraviolet radiation from the Sun. Some chemicals released into the atmosphere by human activity, particularly *chlorofluorocarbons* (CFCs; often used in foam products, air conditioners, refrigerators, and industrial solvents), can destroy ozone and thereby allow more ultraviolet radiation to reach the ground.

In the upper atmosphere CFCs are broken apart by sunlight, releasing their *chlorine* atoms. Under certain conditions chlorine acts as a *catalyst,* whereby each chlorine atom can destroy 100,000 molecules of ozone. In the early 1980s, researchers discovered a significant depletion of ozone occurring each spring over Antarctica (see poster front). At mid-latitudes, the Upper Atmosphere Research Satellite (UARS) recently found significant concentrations of *chlorine monoxide*—a product of ozone depleting reactions. The map at right represents data from one day in January, 1992; darker areas represent higher chlorine monoxide concentrations.



1c Earth System Modeling

We cannot build real models of the Earth; instead, we "build" *numerical models* with a computer. We "construct" the Earth by describing it with numbers. For example, we could divide the Earth's surface into a thousand small areas, and for each area, give a number for elevation above sea level, temperature at a particular time, and so on. Next, we describe the physical, chemical, and biological processes that cause change by programming the computer with mathematical equations representing the laws of nature. The computer can then "run" the model, simulating the functioning of the Earth through time. If the model is constructed well, it can provide new insights into global processes, and may be able to predict future change.



Numerical Modelling.

Case Study: Climate Change

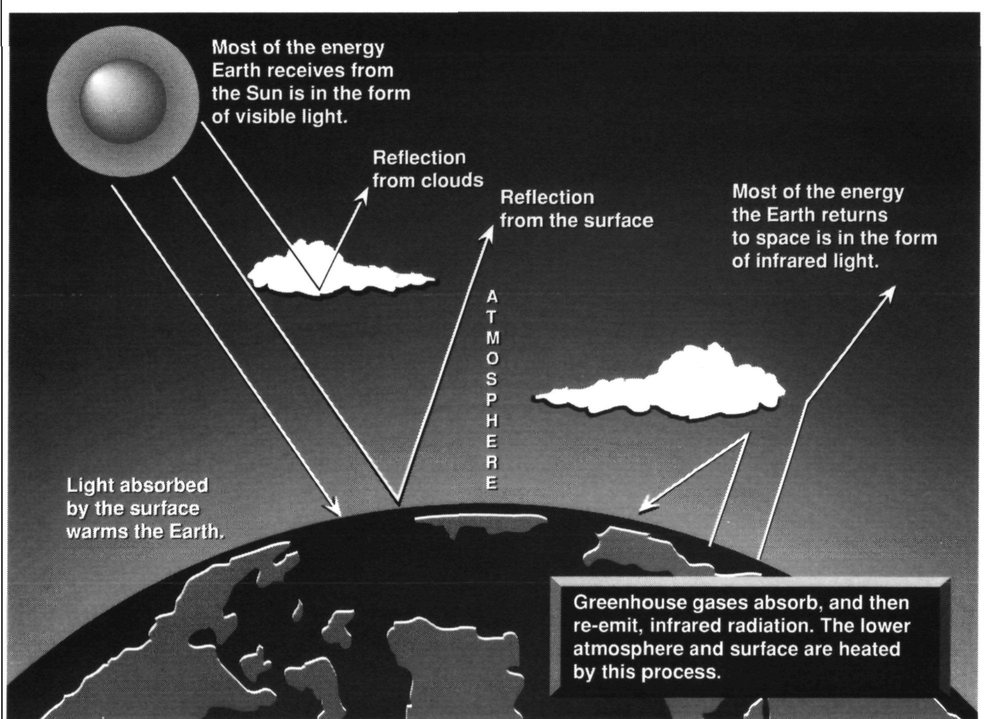
Perhaps the most important question facing our civilization is the extent to which we are altering the climate of our planet. The Earth receives energy from the Sun, and returns an equal amount of energy to space. But most of the sunlight reaching the ground is *visible light,* while the ground returns longer wavelength, *infrared* light toward space. *Greenhouse gases*—gases that absorb infrared (e.g., carbon dioxide, water vapor, methane, CFCs)—act like a blanket, keeping the lower atmosphere warmer than it would be otherwise. This warming process, called the *greenhouse effect,* occurs naturally; without it, Earth would be too cold to support its great diversity of life. But human activity is increasing the concentration of greenhouse gases in the atmosphere, primarily through the burning of fossil fuels (e.g., oil, gas, coal) and the destruction of forests. Will this cause the Earth to become warmer, changing the climate?

Imagine trying to build a numerical model to predict the consequences of humans adding greenhouse gases to the atmosphere. First, how should we divide the Earth to study climate? If we divide it into a thousand areas, will that be enough? A million? Then, we will need details describing every area, such as temperature, wind, rainfall. Next, consider the complexity of interactions that must be programmed into the model. If the climate grows warmer, evaporation will increase, leading to more clouds. Will clouds further enhance the warming because they are made of a greenhouse gas (water vapor), or will they limit warming by preventing sunlight from reaching the ground? How will the biosphere be affected? Will plants thrive with more carbon dioxide in the atmosphere? Or will climate change occur so rapidly that many species, unable to adapt, will be driven to extinction? These are but a few examples of the difficulties in predicting climate change.

Limitations of Models

If we are to use models to help us make policy decisions for the future, we must understand both their usefulness and their limitations. No Earth system model can be perfect because we cannot know every detail of nature, and because even *supercomputers* have limitations. Modeling involves compromises and approximations, choices made by human researchers. Thus, different researchers can legitimately disagree on model predictions. Models are research tools that may be applied skillfully to gain real insight into the global ecology, but the reliability of their predictions cannot be guaranteed.

Models can be invaluable tools. Without them, we might never have recognized many of the dangers facing our environment. But science provides only advice and understanding; it is people who make decisions. We have reached an era of problems on a global scale, requiring global solutions. Our generation has the responsibility of making decisions that will affect the destiny not just of humanity, but of all other organisms that inhabit planet Earth.



Schematic model of the greenhouse effect.

1d For the Classroom

Activity: International Environmental Treaties

Concept: As world population grows, and development expands, pressures on the environment increase. Interactions between nations and peoples assume greater significance. Because environmental problems cross national borders, environmental protection requires international cooperation. Science provides political leaders with information about the nature and extent of environmental damage, but policy decisions must balance ecological ramifications with numerous other concerns. The following activity is designed to show how science, social policy, and political considerations become entangled as we try to preserve our planet. Depending on the depth of research assigned, and the level of sophistication of discussion, the activity can be adapted to middle or high school grades.

Background: The "Montreal Protocol on Substances that Deplete the Ozone Layer," an international treaty signed in 1987 and strengthened in 1990, represents a major breakthrough in global cooperation to preserve our environment. Many nations came together in an effort to protect the ozone layer by setting goals for the elimination of ozone-depleting substances. In addition, provisions were made that acknowledged the special needs of developing countries, and to promote international cooperation in research relating to ozone.

The major provisions of the 1987 protocol were:

- The nations agreed to limit their consumption and production of CFCs: use was immediately frozen at 1986 levels; a 20% reduction (from 1986 levels) was mandated by 1994; a 50% reduction (from 1986 levels) was mandated by 1999. An exception was made for developing countries with low per capita use of CFCs (less than 0.3 kg annually), allowing them an extra 10 years to comply with the treaty limits. Halons, another class of ozone-depleting chemicals, were frozen at 1986 levels with no further reductions required.

- The nations agreed to cooperate to help developing countries replace ozone-depleting chemicals with safe and effective substitutes.

- The nations agreed to discourage or prohibit trade in ozone-depleting substances with nations that did not sign the protocol.

- Provisions were made to allow for changes in the protocol to respond to new scientific knowledge.

In 1990, the protocol was strengthened:

- Required complete elimination of the production and consumption of CFCs *and* halons by 2000 instead of a 50% reduction by 1999 (retaining the delay for developing countries).

- Encouraged recycling of existing ozone-depleting chemicals.

- Established a multilateral fund (financed according to the United Nations scale of assessments) to provide financial assistance to developing countries for replacing ozone-depleting substances.

Procedure: Ask students to roleplay as delegates from different nations to a convention seeking to further revise the Montreal Protocol. You can assign students individually, or in small groups, to nations that represent particular types of interests in the treaty. Some of the key types of interests to represent are:

1. Developed, industrialized countries (e.g., United States, Japan, Western Europe): these are the major producers and consumers of ozone-depleting chemicals. Economic concerns with the treaty include: the need to convert their massive industrial bases to non-ozone-depleting substitutes; the loss of revenue from exports of CFCs, etc.; the possibility of providing financial assistance to poorer countries.

2. Economically poor, industrialized countries (e.g., Russia and other former Soviet Republics; eastern Europe): also will need to convert large industrial bases, but have fewer financial resources to do so than the wealthier countries.

3. Developing countries: generally have little industry to convert, but may have development plans to provide their citizens with amenities, like refrigerators, that currently use ozone-depleting substances. To use non-ozone-depleting substitutes might be more expensive and these nations may need both financial and technical assistance.

4. High-latitude countries (e.g., Australia, New Zealand, Northern Europe): ozone depletion is most serious near the poles, especially near Antarctica. These countries have a special interest in a more rapid phase-out of ozone-depleting chemicals.

Bring the student delegates together, in "roundtable" discussions, to explore the issues listed below. You can add a writing component by asking the students to write specific treaty provisions suitable to all delegates. If you want to go into greater depth, ask students to begin the activity with research on the countries they represent. Pertinent information includes gross national product (GNP), per capita income, current production and use of ozone-depleting chemicals, estimated costs for replacement, and plans for economic development.

1. Recent evidence (like that from the Upper Atmosphere Research Satellite) suggests that the ozone depletion problem may be more serious than recognized in 1990. Discuss possible provisions to eliminate ozone-depleting chemicals prior to the current 2000 deadline.

2. Evaluate and discuss the economic impact of both the current Montreal protocol and possible changes to speed the elimination of ozone-depleting chemicals.

3. Although the Montreal Protocol was signed by the countries that account for most of world's current consumption and production, many developing countries, including China and India, the two most populous, have not yet agreed to participate. Their criticism is that the developed countries enjoyed the benefits of CFCs and other ozone-depleting substances in improving their standards of living; they contend that it is unfair to deny developing countries the advantages these substances offer. Discuss possible provisions that might encourage these developing countries to join in the treaty.

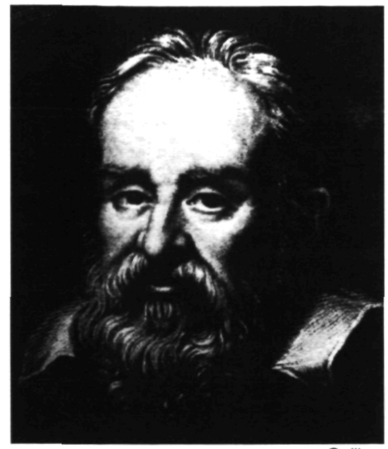
4. Like ozone depletion, climate change induced by greenhouse gases added to the atmosphere is a potential global threat. Ask students to research the positions of the countries they represent with regard to reducing emissions of carbon dioxide and other greenhouse gases. Discuss a possible treaty to reduce the threat of global warming and associated climate change.

2a Our Solar System

Our solar system was formed from a great cloud of gas and dust we call the *solar nebula* about 4.6 billion years ago. As the nebula collapsed due to gravity, rotation flattened it into a disk from which the planets formed. This explains why all the planets orbit the Sun in nearly the same plane and in the same direction. Nearly all of the mass of the solar system (about 99.9%) is contained in the Sun. The remainder makes up the planets, their rings and moons, the asteroids, and the comets. Each class of bodies was shaped by the forces that formed our solar system, but every object exhibits unique features.

Galileo Galilei, 1564-1642

Galileo was an Italian scientist and philosopher, who made the study of nature his life's work. Although he lived at a time when most people still believed the Earth was the center of the universe, his analysis of the motions of the stars and planets led him to support an idea published in 1543 by Nicolas Copernicus: that the Sun is the center of the solar system, and the planets, including Earth, orbit around it. Galileo built and used the first astronomical telescope. With it he observed the Sun, the Moon and the planets and saw that they were more than just lights in the sky; like Earth, they were worlds of substance and dimension. When Galileo first observed the moons of Jupiter, he saw in his discovery a fundamental organizing principle of the solar system—small things orbit large things, and all orbit the Sun.



Galileo

The Inner Planets

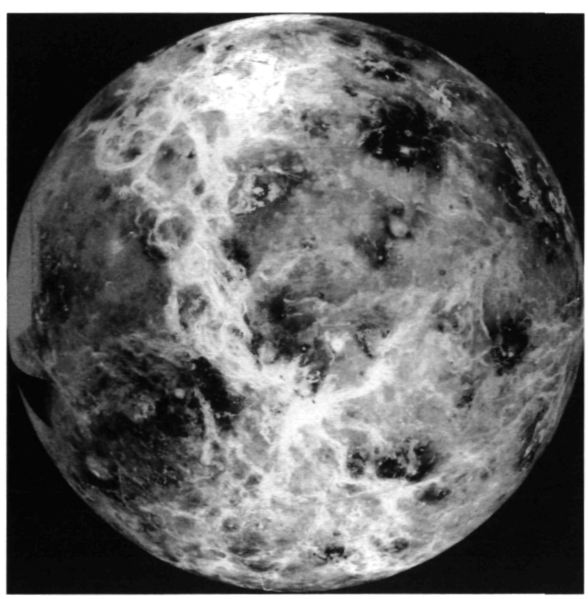
The four inner planets—Mercury, Venus, Earth and Mars—are small, dense, and rocky compared with the giant outer planets. Their surfaces reflect histories of intense *volcanism* and *impact cratering*. Mercury, like our Moon, is pockmarked with craters. Fewer craters are found on Venus, Earth, and Mars, where geological processes and erosion slowly erase the evidence of ancient impacts. Atmospheric processes play an important role on all but Mercury. Mercury and Venus have no moons, Earth has one, and Mars has two tiny moons, called Phobos and Deimos, which may have been asteroids captured by Martian gravity.

The Asteroid Belt

Just beyond the orbit of Mars lies the *asteroid belt*. Here, thousands of asteroids—or "minor planets"—orbit the Sun. Asteroids are made of rock and ice, and come in a variety of shapes and sizes. The largest, Ceres, has a diameter about one-third that of our Moon. Although most asteroids are confined to the asteroid belt, some have orbits that cross other regions of the solar system. Occasionally, an asteroid collides with a rocky planet or moon, or another asteroid.

The Giant Planets

Four *giant planets*—Jupiter, Saturn, Uranus, and Neptune—were formed in the outer, cooler regions of the solar system where the gravity of their solid cores swept up massive amounts of hydrogen and helium gas. Each is orbited by a *ring system* and a host of moons—an average of 14 each. Some moons probably formed with their planet, while others may be captured asteroids. The spectacular rings of Saturn are made up of small icy particles that shine brilliantly in the light of the Sun. The rings around the other giants are darker, perhaps because they have higher concentrations of rock and dust.



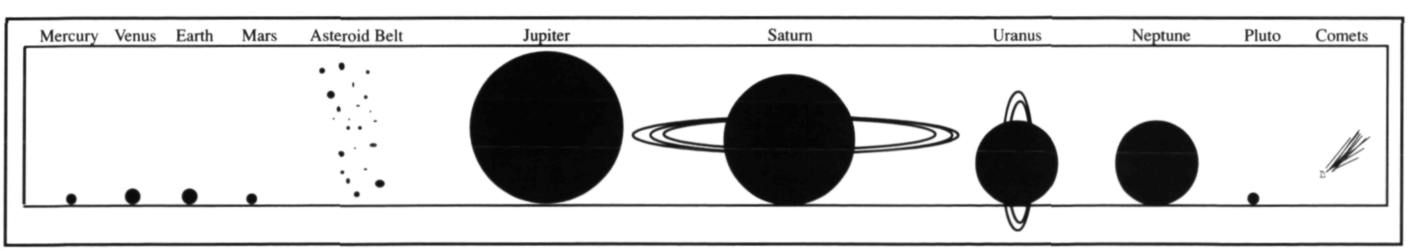
The surface of Venus revealed by radar from the Magellan spacecraft (1991).

Pluto

Little is known about tiny, icy Pluto and its moon, Charon. Pluto is usually the outermost planet. However, it is closer to the Sun than Neptune for about 20 years during each of its 248-year orbit around the Sun; this is the case between 1979 and 1999. Pluto is considered a "misfit" among the planets because it fits the general characteristics of neither the inner planets nor the giant planets.

Comets

Comets are small chunks of icy material, believed to be frozen remnants of the primitive material from which the solar system evolved. Most reside far beyond the orbit of Pluto, but occasionally one will fall in toward the Sun. Evaporation then creates a large cloud around the comet *nucleus,* and pressure from the *solar wind* shapes some of this gas and dust into a long tail pointing away from the Sun. Most comets visit the Sun only once, but a few, like Comet Halley, establish orbits that bring them by the Sun again and again.



Approximate relative sizes of objects in the solar system; asteroids, comet nucleus would be smaller than shown. The diameter of the Sun (not shown) is about ten times that of Jupiter. Distances are not to scale.

2b Planetary Processes

The Earth is a dynamic place: continents drift slowly across the globe; volcanos and earthquakes erupt violently; winds, rain, and the activity of living organisms alter the surface. With the exception of those caused by life, most of these processes probably occur, or have occurred, elsewhere in our solar system. By studying the *planetary processes* that shape other worlds, we develop a new perspective on the evolution of our own.

Planetary processes can be grouped into three broad categories: *internal processes*, like volcanism; *external processes*, like impact cratering; and *atmospheric processes*, like storms and wind. The degree to which each process affects a particular world varies greatly. Worlds without atmospheres, for example, cannot have atmospheric processes; and the giant planets, with their solid cores buried deep beneath layers of liquid and gas, reveal no craters.

Volcanism

Volcanism releases heat and material from a planet's interior onto its surface. On the Earth, molten rock originates deep within the interior, rising through the crust and erupting onto the surface as *lava*. A few volcanos erupt each year somewhere on the Earth. Over time, volcanos, earthquakes, and continental drift—all caused by processes in the interior—completely reshape the Earth's surface. The degree of volcanism and the composition of erupted material varies on other planets and moons.

We have witnessed volcanic eruptions on only two other worlds—Io, a moon of Jupiter, and Triton, a moon of Neptune. However, all of the inner planets and many other moons show evidence of past or present volcanic activity. We can learn about their styles of volcanism by analyzing the sizes and shapes of their volcanos and lava flows. Lava flows that are thin, containing large amounts of dissolved gas, appear smooth after they cool. Thicker flows produce a rougher surface. Large, broad *shield volcanos* form from lava that is erupted quickly and is relatively fluid. On Earth, Mauna Loa (Hawaii) is an example of a large shield volcano. Eruptions of more viscous lava generally form steeper, dome-shaped volcanoes. Lava can also erupt from deep cracks or fissures, creating wide surface layers instead of mountains.

Volcanism on Earth: Mt. Fuji, Japan. (Photo by Willard Price, © 1921 National Geographic Society).

A volcanic eruption on Jupiter's moon Io. Image from Voyager 2.

The Moon

The smooth, dark areas on the lunar surface, easily seen with the naked eye, are called *maria*. The maria are great lava flows that filled large impact basins. The heat of the impacts may have caused lava to flow from the Moon's interior, filling the basin like a great molten lake, then cooling to a smooth surface. Craters seen within the maria were formed by impacts that occurred after the time of the lava flow. Similar examples of smooth plains are found on Mercury, Venus, and Mars, and on many moons in the outer solar system. Long *rilles,* thought to be lava tubes, also are present on the Moon's surface. Hadley Rille, site of the Apollo 15 landing, stretches for 115 km. The long extent of lunar rilles is probably due to the Moon's low gravity.

Venus and Mars

Mars features many giant shield volcanos, including Olympus Mons, the largest mountain in the solar system. The terrific size of Martian volcanos is attributed primarily to two factors: relatively low gravity and the absence of continental drift which allows Martian volcanos to build for longer periods of time than volcanos on Earth.

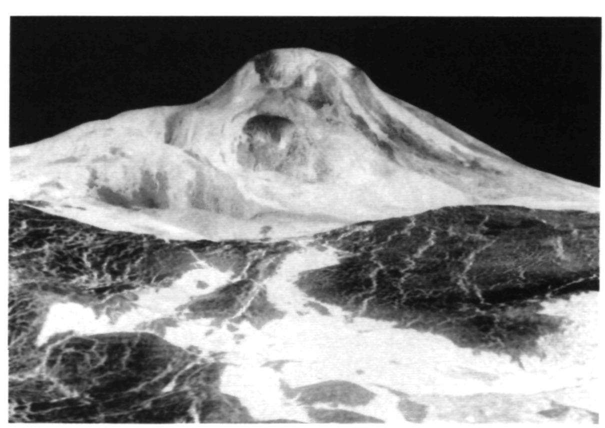
Volcanos on Venus range from broad, shield-shaped structures to steep-sided domes. The shield volcano Maat Mons, thought to be relatively young, stands 8 km high and is the tallest volcano on Venus. Lava flows on Venus can extend for thousands of kilometers, probably because they are made of relatively fluid material, and because the high surface temperature and pressure prevents them from cooling quickly.

Io

Io, the innermost large moon of Jupiter, is the most volcanically active body in the solar system; its surface is completely reshaped in less than a million years. Io's volcanism reveals an interior in turmoil, heated by *tidal friction* from the gravitational effects of Jupiter and a neighboring moon, Europa.

Ice Volcanos

Many of the moons in the outer solar system are more ice than rock, but volcanism still plays a role. Ice volcanos, or geysers, can erupt with water, ammonia, or other gases. Such is the case with the eruptions seen on Neptune's moon Triton, and suspected on the icy worlds of Europa and Ganymede (both moons of Jupiter).



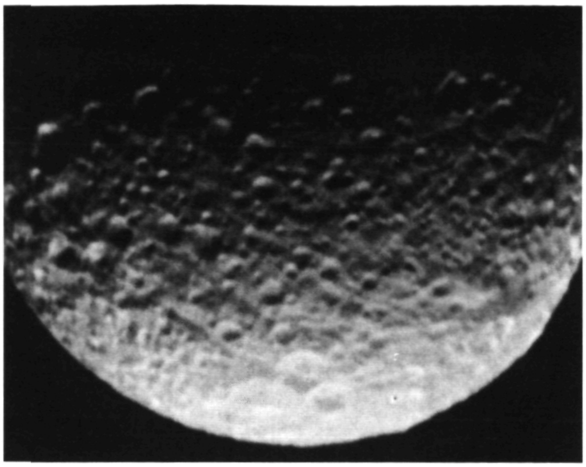
Maat Mons, the largest volcano on Venus. Radar image from the Magellan spacecraft. Vertical relief is exaggerated 22.5 times.

2c Impacts and Atmospheres

Impact Cratering
Asteroids and comets are the debris leftover from the formation of the solar system. When a chunk of this debris violently collides with a planet or moon, it creates an *impact crater*. Early in the history of the solar system, before most of the debris was swept up in collisions, the planets and moons were subjected to a period of intense bombardment. Old surfaces, like Saturn's moon Mimas and the lunar highlands, are densely crowded with impact craters from this early bombardment.

Craters on Earth
Because the Earth and Moon travel together through the same region of the solar system, their cratering rates should have been similar throughout their histories. Today we see far more craters on the Moon than on Earth, suggesting that most of the ancient impact craters on Earth have been erased by geological activity or erosion. Those that remain—of which more than 100 are known—usually are hidden by forest cover, water, or ice.

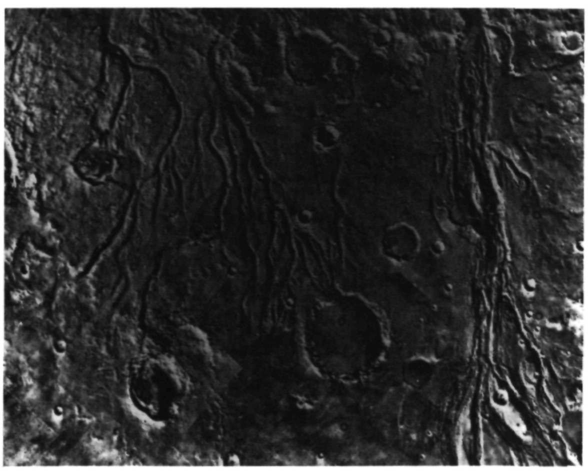
Atmospheric Processes
Atmospheric processes are all that we can see on the giant planets (Jupiter, Saturn, Uranus, Neptune), which are composed mostly of hydrogen, helium, ammonia, and methane. Their atmospheres are dynamic, with typical wind speeds 10 times those found in the most



Saturn's moon Mimas is heavily cratered, indicating an ancient surface. Image from Voyager 2.

severe storms on Earth. Giant storms, like the Great Red Spot of Jupiter or the Great Dark Spot of Neptune, can be larger in diameter than the Earth.

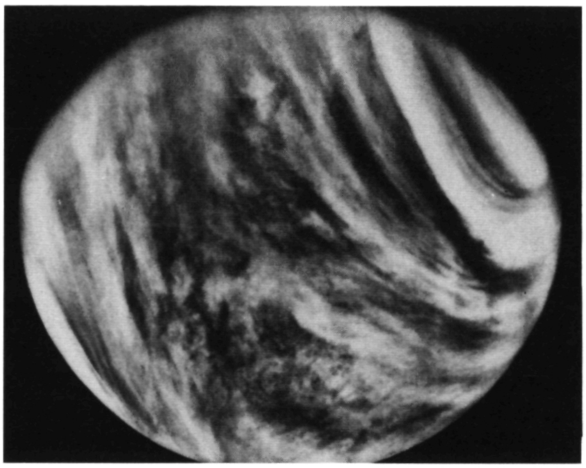
Atmospheres, in the form of thin layers of gas surrounding solid worlds, also affect the surfaces of Venus, Earth, Mars, and Saturn's moon Titan. The atmospheres of Venus and Mars are made mostly of carbon dioxide; Earth's is mostly nitrogen and oxygen; and Titan's is mostly nitrogen, argon, and methane. We have seen evidence of wind and weather, processes we know well on Earth, on both Venus and Mars; we have not yet seen through Titan's cloud cover. Wind erosion can be seen around mountains and craters on both Venus and Mars. Sand dunes on Mars, and the great *Martian dust storms*, are other examples of the effects of atmospheric processes.



Channels, apparently carved by flowing water, on Mars. Image from Viking Orbiter.

Climate Cycles: Earth and Mars
Evidence for long-term *climate cycles* is found on both Earth and Mars. On Earth, great ice ages have occurred, marked by the advance of glaciers, while other periods have been so warm that even the poles are ice-free. Similar climate cycles may occur on Mars, where the atmospheric pressure is so low that liquid water would instantly evaporate. Yet the surface of Mars has numerous channels that appear to have been cut by flowing water. Though now in an ice age, Mars has had epochs when warmer temperatures brought a denser atmosphere and abundant rainfall .

The Greenhouse Effect: Earth and Venus
The *greenhouse effect* is a process where *greenhouse gases,* like carbon dioxide, trap heat and warm a planet's surface. If Venus had an atmosphere like the Earth, it would be only slightly (about 20° C) warmer because it is nearer the Sun. Instead, its thick atmosphere of carbon dioxide creates surface temperatures of 450° C—hotter than the hottest kitchen ovens. A natural greenhouse effect operates to a lesser extent on Earth, but human activity threatens to enhance its action by adding carbon dioxide and other greenhouse gases to the atmosphere. Thus, Venus provides an important perspective on Earth's environment.



Cloud-covered Venus. Its high surface temperature is a result of the greenhouse effect. Image from Pioneer Venus Orbiter.

Impacts and Life
Asteroid or comet impacts can play a major role in biological evolution and have been implicated in several major extinctions in the Earth's history. Our own existence may in part be the result of an impact that occurred 65 million years ago. In this scenario, an impact blasted huge amounts of material into Earth's atmosphere, creating a worldwide dust cloud that blocked sunlight, cooled the surface, and prevented plant photosynthesis. As plants died, the entire food chain was disrupted, leading to the extinction of more than half the species then living, including the dinosaurs. Their demise provided an opportunity for mammals, and ultimately humans, to evolve.

2d For the Classroom

Activity : Jupiter's Satellite System

Concept: Jupiter has nearly the same composition as the Sun, but only about 1/*1000* the mass. With its host of satellites, and its intense electrical and magnetic activity, Jupiter is in some ways like a small star at the center of its own miniature solar system. Its four largest satellites (moons)—Io, Europa, Ganymede, and Callisto—are known as the *Galilean* moons because of their discovery by Galileo in 1610. This activity asks students to make a scale model of the Jovian system.

Jupiter's Satellites

Note: Because of the large distances and relatively small diameters of the moons, it may not be possible to use the same scale for both. It is important to first determine the size of the display area and then determine your appropriate scale. If you choose to use different scales, discuss the reasons with students or let them discover why using the same scale is not practical. Examples shown use the following scale: 1 centimeter = 1,000 kilometers.

Satellite	Distance from Center of Jupiter (km)	Scaled Distance (1cm=1000km)	Diameter (km)	Scaled Diameter (1cm=1000km)
Metis	128,000	1.28 m	40**	.04 cm
Adrastea	129,000		25**	
Amalthea	181,000		270	
Thebe	222,000		100**	
Io	422,000		3,620	
Europa	671,000		3,140	
Ganymede	1,070,000		5,260	
Callisto	1,883,000	18.8 m	4,800	4.80 cm
Leda	11,094,000	110.9 m	16**	0.016cm
Himalia	11,480,000		180**	
Lysithea	11,720,000		40**	
Elara	11,737,000		80**	
Ananke*	21,200,000		30**	
Carme*	22,600,000		44**	
Pasiphae*	23,500,000		70**	
Sinope*	23,700,000		40**	

* Retrograde orbit ** Uncertain by more than 10 percent

Additional Data:

Jupiter: diameter (at equator) = 142,796 km; avg. distance from Sun = 778,300,000 km

Jupiter's rings: distance from center of Jupiter is about 194,000 km; rings are thin and lie in equatorial plane.

The Sun: diameter = 1,392,000 km

The Earth: diameter (at equator) = 12,756 km; avg. distance from Sun = 149,600,000 km

Procedure:

1. Help students use the data table to determine the scaled diameters and distances from Jupiter for each of the moons and the size of Jupiter itself. You might choose a different scale than given in the example, depending on the space available in your classroom.

2. Make each scale model moon out of clay or some similar material. (Option: instead of making 3-dimensional models, draw 2-dimensional models of the moons on paper.) The large moons should be spherical. Smaller moons come in a variety of shapes, and some will be so small that they should be represented by just a very tiny dot. Jupiter can be made in a variety of ways. One simple method is to use a wire mesh (e.g., chicken wire) to make a sphere of the right size, then cover it with papier-mâché. Alternatively, a 2-dimensional Jupiter could be drawn on a large piece of paper. Students may draw and color features of Jupiter and the four Galilean satellites.

3. Select a large display area such as a school hall, cafeteria, or playground. Place Jupiter at one end. Have students measure the correct scale distances for the satellites and put them in their correct positions. Option: Go outside and have students "be" moons (holding the models). One student should be Jupiter, in the center. Others should be moons, standing at the correct distances from Jupiter. If students want to "orbit" remember that, as viewed from above Jupiter's north pole, all of the moons go around Jupiter counter-clockwise, except those labelled retrograde (clockwise).

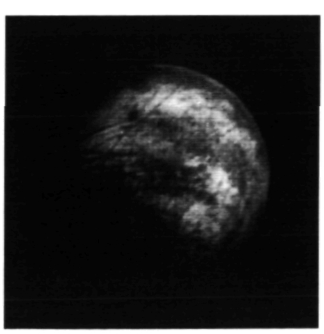
4. *Additional options:* Figure out the distance of Jupiter's rings, and use a ribbon to place the rings in the model. Figure out the size of the Earth on the same scale, and make a model of it for comparison. Compare the size of the Sun to Jupiter, and determine where the Sun would be located in the model.

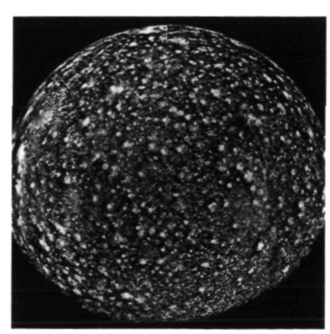
Discussion Questions:

1. By studying the sizes of the satellites, try to guess which ones were born in the Jupiter system, and which are more likely to be captured asteroids.

2. Jupiter has nearly the same composition as the Sun, but it is not a star because its internal temperature and pressure are too low for fusion reactions. Why do you think that the Sun became hot and dense enough to start fusion (thus becoming a star) while Jupiter did not? (Hint: think about the effects of their relative masses and gravity; internal temperature and pressure depend on the weight of overlying material.)

3. Research similar data on the satellite systems of other planets, and make similar models. Compare the satellite systems of different planets. Why do you suppose the inner planets have so few satellites?





The Galilean Moons... Io

Europa

Ganymede

Callisto

3a The Scale of the Universe

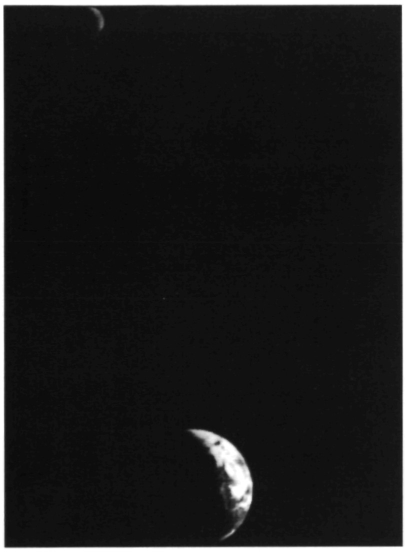
"How vast those Orbs must be, and how inconsiderable this Earth, the Theatre upon which all our mighty Designs, all our Navigations, and all our Wars are transacted, is when compared to them. A very fit consideration, and matter of Reflection, for those Kings and Princes who sacrifice the Lives of so many People, only to flatter their Ambition in being Masters of some pitiful corner of this small Spot."

— Christiaan Huygens, c.1690

A light-year is the *distance* (it is not a unit of time) that light can travel in one year. Since all light (i.e., radio, microwaves, infrared, visible, ultraviolet, X-rays, and gamma rays) travels at the *speed of light*, 300,000 km/s, a simple unit conversion shows that light travels about 9.5 trillion km in one year (multiply the speed of light by the number of seconds in a year):

$$300{,}000\,\frac{\text{km}}{\text{s}} \times 60\,\frac{\text{s}}{\text{min}} \times 60\,\frac{\text{min}}{\text{hr}} \times 24\,\frac{\text{hr}}{\text{day}} \times 365\,\frac{\text{day}}{\text{yr}} = 9.5\text{ trillion}\,\frac{\text{km}}{\text{yr}}$$

Thus, saying "one light-year" is just an easy way of saying "9.5 trillion km."



The Earth and Moon, together in space (Voyager 2).

Every culture has looked to the skies for inspiration, and longed to understand how we fit into the grand scheme of the universe. For most of human history, our ancestors believed that the Earth—and by implication, humanity—was at the center of the universe. It is only about 400 years ago, with the work of Copernicus, Kepler, and Galileo, that we finally recognized that the Earth is just one planet revolving around our Sun. Since that time, our understanding of the universe has grown tremendously. Today, we can fulfill an ancient dream: we can accurately describe the physical place of the Earth in the universe.

The Solar System

Each day, the Earth spins once on its axis; as it does, we see the Sun, Moon, planets, and stars appear to rise and set in our sky. The Earth, travelling together with the Moon, make one orbit of the Sun each year. Eight other planets, plus numerous moons, asteroids, and comets, orbit the Sun as well.

To get an idea of the scale of our solar system, consider: If the Sun were the size of a grapefruit (14 cm diameter), the Earth would be orbiting about 15 meters away, barely as large as a pinhead. The rest of the planets—with even the largest, Jupiter, no bigger than a marble—would be spread out within about 3/4 km of the Sun. Yet the nearest stars, grapefruit-sized, would be thousands of kilometers away.

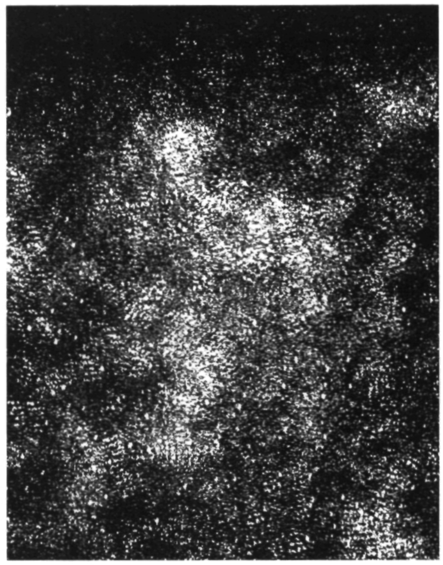
The Milky Way Galaxy

Our Sun is just one of several hundred billion stars that make up the disk-shaped, spiral system of stars we call the *Milky Way.* Stretching 100,000 *light-years* in diameter, the entire Galaxy is slowly rotating. Our solar system is located near the outskirts, about 25,000 light-years from the galactic center, completing one orbit every 200 million years. In the region of our Sun, each star is separated from the others by enormous distances—on the scale above, the stars are like grapefruits thousands of kilometers apart. By contrast, on the scale of the diagram representing the Milky Way, the period at the end of this sentence would contain a million star systems.

Artist conception of the Milky Way.

The Universe

The Milky Way is only one of some ten billion galaxies in the *observable universe.* The Milky Way is part of the *Local Group*—



Artist conception showing great archipelagos of galaxies stretching across the universe.

about 20 to 30 galaxies located within 3 million light-years of one another. Galaxies are like islands of stars, gas, and dust in space. Most galaxies are found in small *groups,* with a few tens of members, or in larger *clusters* with a few hundred to a few thousand galaxies. These, in turn, are grouped into *superclusters* that stretch like giant archipelagos for hundreds of millions of light-years across the universe.

The universe has no center and no edges. The part that is observable by us is limited by the age of the universe, presently thought to be between 10 to 20 billion years. If, for example, our universe is 15 billion years old, then light from galaxies more than 15 billion light-years away would not have had time to reach us; our observable universe would be about 15 billion light-years in radius.

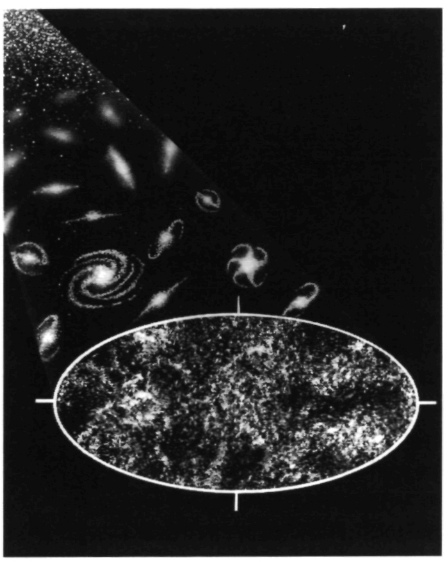
3b Origins of the Universe

The Crab Nebula: an expanding cloud from a supernova, the explosive death of a massive star. (Lick Observatory)

Where do we come from? How did the universe begin? History is rich with stories attempting to answer these questions. In the past few decades, aided by telescopes on the ground and in space, we have made great strides toward answering these ancient questions.

The Expanding Universe

During the 1920s, while studying distant galaxies with what was then the world's largest telescope, Edwin Hubble made one of the most astonishing discoveries of all time: the entire universe is expanding. The evidence for the expanding universe is two-fold: One, outside of the Local Group of galaxies, which remains bound together by gravity, every other galaxy cluster in the universe is moving away from us. Two, the farther away the cluster, the faster it is moving. Anyone looking out at the rest of the universe, from any location in any galaxy, would see the same effects from the universal expansion.



Artist conception of the expanding universe.

The Big Bang

If the universe is expanding, then it must have been smaller in the past. It seems reasonable to assume that, at some past time, the entire universe was concentrated at a single point. This point suddenly exploded, out, leading to everything we know in the universe today. We call this moment, the birth of our universe, the *Big Bang*. By extrapolating the current expansion rate of our universe back in time, we can estimate that the Big Bang occurred between 10 and 20 billion years ago.

The universal expansion is not the only evidence for the Big Bang. The theory has been used to predict a number of phenomena, many of which are now verified by observation. The foremost example is the detection of the remnant radiation from the heat of the Big Bang. This remnant, called the *cosmic background radiation*, was theoretically predicted more than a decade before its discovery in 1964.

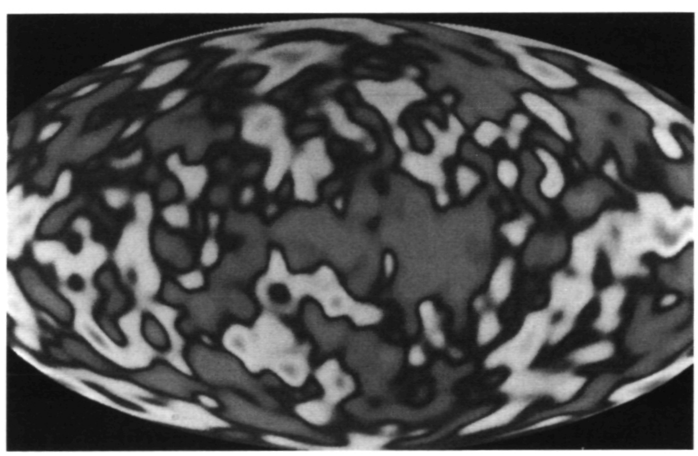
Galactic Ecology

As the universe expanded and cooled, higher density regions—"seeds" planted in the Big Bang itself—collapsed under gravity to form the largest structures in the universe: superclusters and clusters of galaxies. Within individual galaxies, a complex *galactic ecology* began. Stars form from clouds of gas and dust in the galaxies, and die in violent explosions that return stellar material to the *interstellar medium.* Stellar light bathes the galaxy with radiation, heating the interstellar material. Stellar winds, and shocks from stellar explosions, cause new clouds to form, which then collapse, and give birth to new generations of stars. The early universe contained only hydrogen and helium. All other elements, including those that make up the Earth and its living organisms, were produced by stars.

> *"We are star stuff."*
>
> — Carl Sagan

Fossils From the Big Bang

During the first few thousand years after the Big Bang, the universe was so hot and dense that radiation inevitably was scattered by nearby particles of matter. If we could look inside this early universe, we would see just a bright, impenetrable "fog" of light; it would be much like being deep inside of a star. A few hundred thousand years after the Big Bang, however, the universe cooled enough so that light could travel freely through space. It is the light from this epoch that we see today, in the form of microwaves, as the *cosmic background radiation.* We will never be able directly to see light from before the first few hundred thousand years, but the cosmic background contains relic structure from earlier epochs. Studying this structure is like looking at fossils from the very early universe.



The map to the right, compiled with data from NASA's *Cosmic Background Explorer,* shows the structure of the cosmic background over the entire sky. The map is analogous to a flat map of the Earth: imagine bending the map into a sphere around you; in each direction you look, the map shows you the cosmic background radiation. The contrast on the map is highly exaggerated in order to show structure—the light patches are only about one hundredth of one percent warmer than the dark patches. The map shows a critical link between the Big Bang and the present-day universe: the structures observed in the cosmic background were the seeds for the large-scale structure, the great archipelagos of galaxies, in our universe today.

3c Mission to the Universe

Like the ancient cartographers who compiled data returned from voyages of exploration, astronomers have for centuries compiled observations collected with telescopes. The cartographers eventually succeeded in making maps, crude at first, of the entire surface of the Earth. Today, we are on the verge of completing the first truly comprehensive maps showing the structure of the entire observable universe, in every wavelength of light. The data are being collected by nearly two dozen space observatories, built and operated with contributions from scientists and engineers from most nations on Earth. In support of International Space Year, astronomers from around the world have dubbed this effort *"Mission to the Universe."*

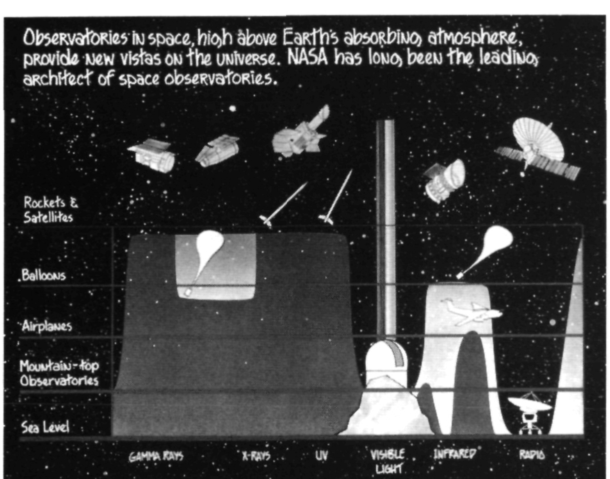
The Universe from Space

The advent of observatories in space has revolutionized our ability to explore the universe. The visible light that our eyes can see is only a very tiny part of the complete *electromagnetic spectrum.* Each portion of the spectrum reveals new insights into the cosmos but, with the exception of visible light and radio wavelengths, most of the spectrum is blocked by Earth's atmosphere. Thus, we can get a complete picture of the universe only by placing observatories in space. In addition, even visible-light observations are enhanced from space, since the natural turbulence of our atmosphere tends to blur images of distant objects.

Seeing into the Past

Perhaps the most remarkable fact about any astronomical telescope is its ability to peer not only into the depths of space, but into the depths of time. Because it takes time for light to cross the vast expanses of space, the light that reaches us shows objects as they were in the past, when their light first left. For example if we study a star whose light traveled for 10 years to reach us (i.e., it is 10 light-years distant), then we are studying the star as it was 10 years ago. The more distant the object lies, the farther back in time we see.

Because light from very distant objects takes so long to reach us, we see the objects as they were in the distant past—when the universe was much younger than it is today. Thus, we can directly observe conditions in the early universe simply by looking to great distances in space. We learn how our universe has evolved by comparing objects from the young universe (i.e., at great distances) with similar objects from the universe of today (i.e., nearby). Quasars, for example, are sources of extreme energy buried in the cores of some galaxies; because the most energetic quasars are found only at great distances—billions of light-years—they may represent a stage in galactic evolution that is eventually outgrown.

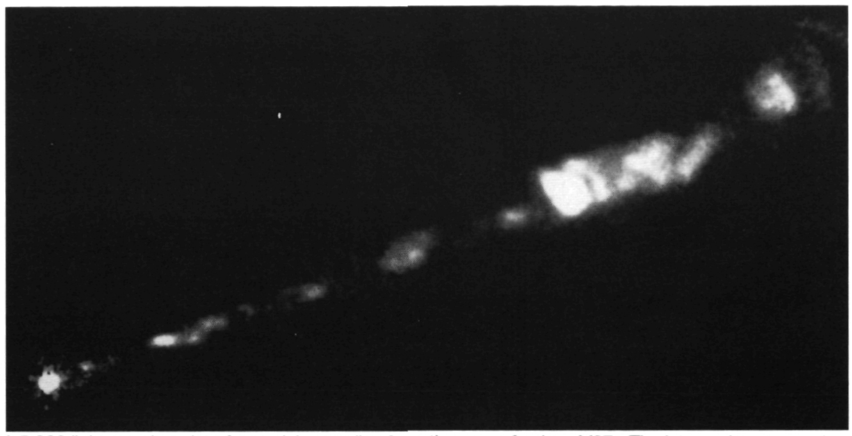


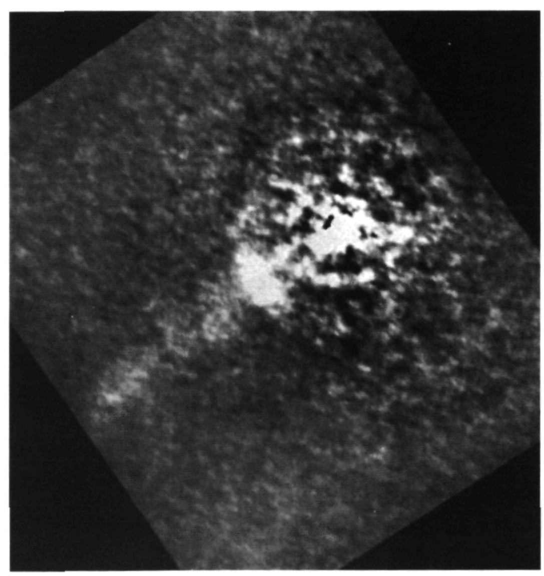
Most of the spectrum can be observed only from space.

Black Holes

According to Einstein's *theory of relativity,* the very structure of space and time— *space-time*—is "warped" by matter to produce the effect of gravity. In a sense, the presence of a large mass causes space to be curved in much the same way that a bowling ball lying on a trampoline causes the stretched fabric to bend; the difference is that the trampoline is 2-dimensional, while space is 3-dimensional (and space-time is 4-dimensional). In regions where space-time is bent, light will travel along a curved path, and time will run slower than it does in flatter regions. The stronger the gravitational field, the more the light will be bent, and the more time will slow down.

Could there be a place where the gravitational field is so strong that light cannot escape, and time comes to a stop? We would call such a place a *black hole.* Using the bowling ball and trampoline analogy, a black hole is a place where the fabric has been stretched so far that it has broken through; it is truly a hole in the fabric of space-time. Many scientists believe that black holes are common throughout the universe.


A 5,000 light-year long jet of material extending from the core of galaxy M87. The jet may be powered by the release of gravitational energy as matter falls onto a black hole with the mass of a billion suns. (Hubble Space Telescope)


Quasar PKS 021-36, with a "jet" of material shot out from its core. (Hubble Space Telescope)

3d For the Classroom

Activity 1: Scale of the Solar System

Concept: Even our own solar system can seem incomprehensibly vast. We can begin to get a feel for its scale, however, by making a scale model of the solar system.

Procedure: (1) Help students to calculate diameters and distances from the Sun, for each object, using a scale of 1 to 10 billion, or 1 cm = 100,000 km. Remember that a light-year is about 10,000,000,000,000 (ten trillion) km. (2) Find ordinary materials of the right sizes to represent the Sun and the planets. For example, the Sun can be a grapefruit; Jupiter a marble; the Earth a ball point from a pen. (3) Find an area where you can take your students on a walk from the Sun to Pluto, on this scale. Starting at your model Sun, pace out the distances to each planet. Stop at each planet location, to study the model planet and look back toward the model Sun. (Option: Discuss characteristics of each planet as you reach each location.) (4) Using a world map, find the location of the nearest stars on this scale.

Table for Activity 1

Object	Diameter (km)	Avg. Distance from Sun (km)
Sun	1,392,500	---
Mercury	4,880	57,900,000
Venus	12,100	108,200,000
Earth	12,760	149,600,000
Mars	6,790	227,900,000
Jupiter	143,000	778,300,000
Saturn	120,000	1,427,000,000
Uranus	52,000	2,870,000,000
Neptune	48,400	4,497,000,000
Pluto	2,260	5,900,000,000
nearest stars*	---	4.3 light years
center of Milky Way	---	25,000 light years

* There are three stars that orbit each other in the nearest star system, called Alpha Centauri. The largest is roughly the same size as the Sun, while the other two are slightly smaller.

Discussion: A lively debate can be generated after the walking tour. Some sample topics: (1) Ask students to discuss how they feel upon seeing the scaled size of the Earth in the solar system. Older students can be asked to discuss their interpretation of the quotation from Christiaan Huygens on panel 3A. (2) Discuss environmental issues and the fragility of the Earth, after seeing it to scale. (3) Discuss the vast distances to the stars. Why is it so difficult to detect planets, if they exist, around other stars? (4) Could this same scale be used to make a model of the Milky Way? Discuss suggestions of how a scale model of the Milky Way might be made.

Activity 2: Counting the Stars

Concept: Estimates of the number of stars in the Milky Way vary from about one hundred billion to more than one trillion. With its vast size, the scale used for the solar system is inadequate for trying to comprehend the Galaxy. Instead, we consider how long it would take to count a hundred billion stars.

Procedure: (1) Ask your students to guess (without calculating) how long they think it would take to count out loud to 100 billion. You may find a lively debate on the question, with estimates ranging from hours to centuries. (2) Help students estimate how long it would really take. Ask them to assume they can count one per second, with no breaks, so that it would take 100 billion seconds. Show them how to convert this into years.

$$100{,}000{,}000{,}000 \text{ s} \div 60\frac{\text{s}}{\text{min}} \div 60\frac{\text{min}}{\text{hr}} \div 24\frac{\text{hr}}{\text{day}} \div 365\frac{\text{day}}{\text{yr}} = 3{,}171 \text{ yr}$$

Discussion: Are they surprised by how long it would take? Discuss the enormous size of the Galaxy, remembering that individual stars are separated by enormous distances (as shown in the previous activity). How long would it take to count a trillion stars? How long would it take to study all of those stars? To visit them? To find out if they have life-bearing planets?

Activity 3: The Cosmic Calendar

Concept: Astronomer Carl Sagan developed the concept of the cosmic calendar to help explain the scale of time. The cosmic calendar is like a scale model, representing the entire history of the universe as a single year. The Big Bang takes place at the first stroke of midnight on January 1; and the present is the last instant before midnight on December 31. On this scale, all of written human history takes place in only the last ten seconds.

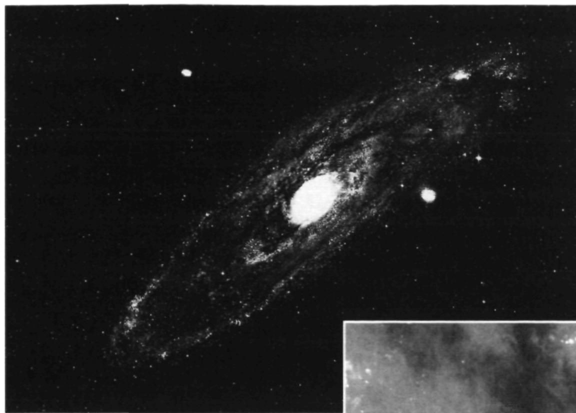
The Scale: Estimates of the age of the universe range from 10 to 20 billion years. For the cosmic calendar, take the average, 15 billion years. Thus, the scale is: 1 year = 15 billion years; 1 month = 1.25 billion years; 1 day = 41 million years; 1 hour = 1.7 million years; 1 minute = 28,500 years; 1 second = 475 years.

Procedure: (1) Begin by asking students to figure out the scale, as above. (2) Break students into groups of 3 to 5, and ask each group to make a cosmic calendar. Allow students creative freedom to make their calendars as comprehensive and artistic as possible. (3) Ask students to calculate the dates of significant events, and to mark them on their calendars. A few events are listed below; students can do research to add other events. (4) Discuss their calendars when they are finished. If you wish, you might have students vote on which group produced the best calendar.

Some Significant Events for Activity 3

Galaxy formation	10 to 15 billion years ago
Formation of our solar system	4.6 billion years ago
Oldest fossil evidence of life of Earth	3.5 billion years ago
First animals and plants on land	600 million years ago
Earliest dinosaurs	200 million years ago
Extinction of dinosaurs	65 million years ago
Earliest humans	2-3 million years ago
Cave paintings	10-30,000 years ago
Agriculture, villages	10,000 years ago

4a Our Star

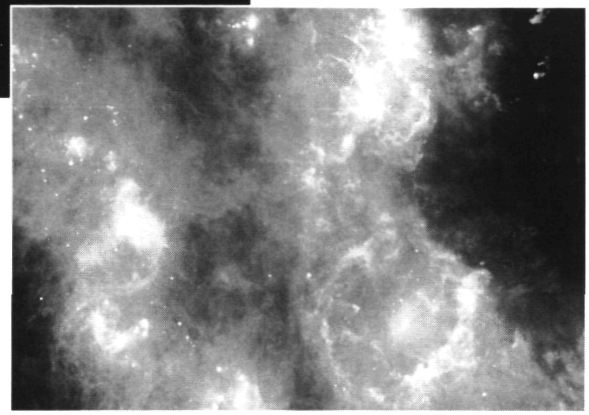


The great galaxy in Andromeda. Like our own Milky Way, it contains several hundred billion stars. If this were the Milky Way, the Sun would lie somewhere in the outskirts, too dim to be seen. (Lick Observatory)

From the dawn of history, our ancestors marveled at the stars sparkling in our night sky. Only within the last few hundred years, however, have we recognized that our Sun is simply one among the stars. Its startling radiance, providing the warmth and light that bathes our globe, is due only to the fact that it is, by a factor of a million, the nearest of all stars.

The few thousand stars visible to the naked eye are just some of the nearest and brightest among several hundred billion stars in the Milky Way. The vast majority are similar to the Sun in size, temperature, and constancy of light. We are fortunate that the Sun is so ordinary. The extraordinary stars are interesting to study, but probably present conditions too extreme to support life in their solar systems.

Ordinary stars, like our Sun, are made mostly of hydrogen (about 3/4 of the Sun's mass) and helium (about 1/4), with much smaller amounts of heavier elements like carbon, oxygen and iron. Throughout most of their lives, stars generate energy by fusing hydrogen into helium; near the end of their lifetimes, however, they can fuse heavier elements.



Stars being born today in the Orion nebula. The birth of our own Sun probably was similar. (Infrared Astronomical Satellite [IRAS])

What is a Star?

Stars are great balls of hot gas that are really just giant nuclear reactors, producing energy by the *fusion* of light elements into heavier ones. (In contrast, human-made nuclear power plants generate energy by the *fission* of heavy elements into lighter ones.) Fusion occurs deep in the core, where temperatures reach tens of millions of degrees. A star is "born" at the moment that it first begins nuclear reactions in its core and dies when its fusion reactions cease.

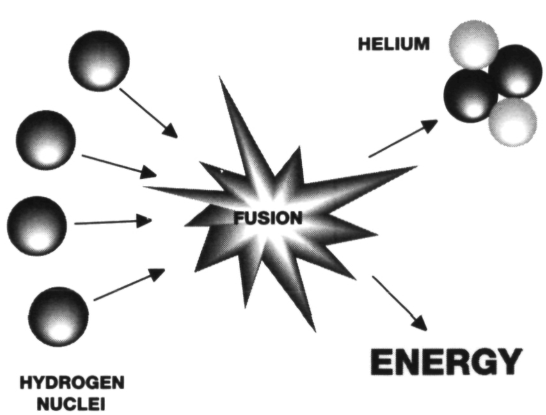
Formation of the Sun

Our Sun formed about four and one-half billion years ago from a great cloud of gas and dust made up of material recycled from earlier generations of stars. Over a period of millions of years, gravity caused this *solar nebula* to condense. The dense center of the solar nebula became the Sun, while rotation formed a disk of material that became the planets. As gravity forced the Sun ever smaller, the pressure and temperature of the Sun's interior rose until nuclear fusion was ignited in the core.

$$E = mc^2$$

(E = energy; m = mass; c = the speed of light = 300,000 km/s)

Einstein's famous equation tells us that small amounts of mass can be converted into large amounts of energy (and vice versa). Hydrogen fusion, the power of the stars, combines four hydrogen nuclei into a single helium nucleus. In this process a small amount of mass is converted into energy. In our Sun, fusion turns about 600 million tons of hydrogen into 596 million tons of helium every second. The "disappearing" four million tons of matter becomes energy.

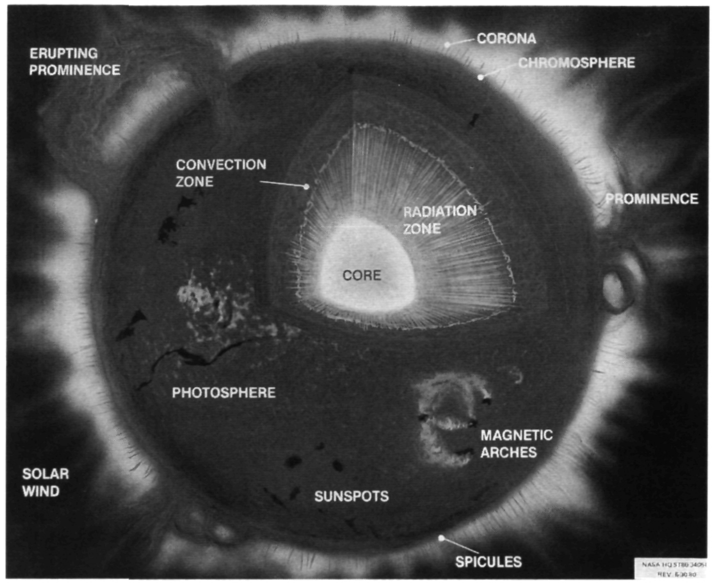


The Sun's Future

The Sun has enough hydrogen in its core to continue nuclear fusion, allowing it to shine steadily for another five billion years. Then, with its core converted to helium, it will begin to expand into a *red giant* star, growing so large that it will engulf the Earth. Over the following billion years, the Sun will fuse its helium into carbon and undergo a succession of expansions and contractions. Eventually, it will expel its outer layers into space where they will be available for recycling into future generations of stars. Its core, by then made of carbon, will shrink under gravity to about the size of the Earth, yet still contain much of the mass of the Sun. This dense corpse of the Sun will at first glow as a hot, *white dwarf* star. Then it will slowly cool until it is but a cold, dark cinder in the Milky Way.

The Ring Nebula. The star at the center is a white dwarf that has expelled its outer layers into space. Our Sun will do the same in about five billion years. (Lick Observatory)

4b Understanding the Sun



All solar energy is generated by hydrogen fusion deep in the Sun's core. Understanding the Sun is a matter of tracing the *transport* of energy through the Sun and then out into space.

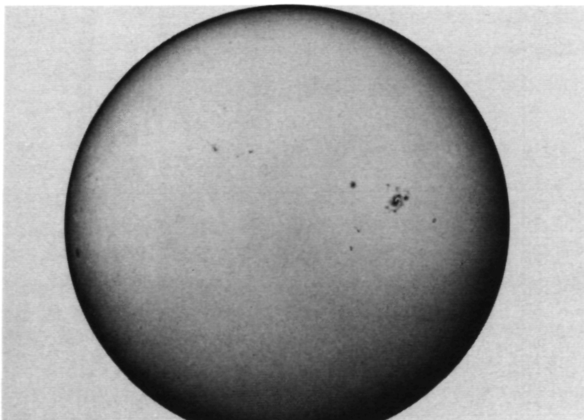
Inside the Sun

Most energy from fusion is released in the high energy form of radiation called *gamma rays*. Throughout most of the solar interior, this energy bounces around among particles in the *radiative zone*, constantly being absorbed and re-emitted. As the energy works its way toward the surface, it slowly degrades into lower energy radiation. About three-quarters of the way out, this radiation heats the cooler, outer layers, creating *convection*. In the *convection zone*, some of the energy is transported outward by the rising of warm gas and the sinking of cool gas. The entire process is long; the energy we receive from the Sun today was produced by fusion reactions that took place hundreds of thousands, or millions, of years ago.

The Surface of the Sun

The Sun is gaseous throughout; an object falling into the Sun would never encounter a definite "surface." The visible surface of the Sun, or *photosphere*, is simply the layer of gas from which most of the energy escapes as light into space. Travelling at 300,000 km per second (the speed of light), light from the photosphere only takes about eight minutes to reach the Earth.

The photosphere looks substantial, but is actually far less dense than air (by a factor of 500 compared to sea-level air). By earthly standards, it is very hot—about 5,000-6,000 Kelvin—but it is the coolest layer of the Sun. Detailed images of the photosphere reveal a complex structure. It has a mottled appearance called *granulation*. Each "granule" represents the top of a convection cell, bright where hot gas is welling up from the interior and dark where cooler gas is sinking back down. The most notable photospheric structures are *sunspots:* regions of gas, slightly cooler than their surroundings, which are shaped by strong *magnetic fields*. Individual sunspots typically are several times the size of the Earth.



The photosphere, dotted with sunspots. On closer inspection, we see the granulation of the photosphere. (Smithsonian Institution)

The Chromosphere and Corona

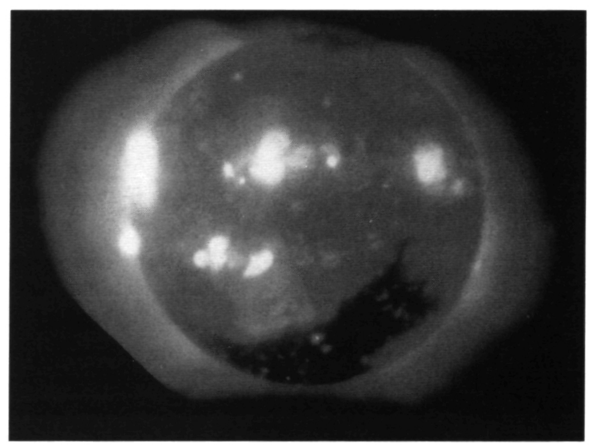
The temperature and density of the Sun decrease from extremely high values in the Sun's center to much lower values in the relatively cool and tenuous photosphere. Above the photosphere, densities continue to decrease in the *chromosphere* and *corona*. Surprisingly, however, temperatures rise as we move outward through these layers. Just what makes them hotter is one of the great mysteries in stellar/solar astrophysics.

The chromosphere, with temperatures of up to tens of thousands of degrees (Kelvin), shines predominantly in ultraviolet light. The corona, at a million degrees or more, shines predominantly in X-rays. From the ground the corona only can be seen during a total eclipse, when it appears as an ethereal, shimmering halo around the eclipsed solar disk.

Unlike the relatively steady photosphere, the chromosphere and corona are highly variable. Immense bursts of light called *solar flares* are most easily seen in the chromosphere. Flares are caused by the sudden release of energy stored in the complex, twisted magnetic fields above sunspots, much like energy stored in a twisted set of rubber bands. Giant *prominences,* huge streams or loops of gas, sometimes rise through the chromosphere and corona. Also shaped by magnetic fields, prominences may survive as long as a few weeks.

The Solar Wind

Material from the solar corona expands outward in a flow of atomic particles called the *solar wind*. Though its density is so low we would consider it a good vacuum here on Earth, the solar wind has real effects on the worlds of our solar system. Comet tails, for example, always point away from the Sun, blown by the solar wind. The solar wind sweeps outward from the Sun, with velocities ranging from 350 to 700 kilometers per second. Because the Sun rotates, approximately once every 27 days, the solar wind blows in a complex spiral pattern. Its shape is distorted by the huge eruptions of flares and other energetic solar phenomena. Because the solar wind extends throughout the solar system, the Earth, like the other planets, effectively lives in the extended outer atmosphere of the Sun.



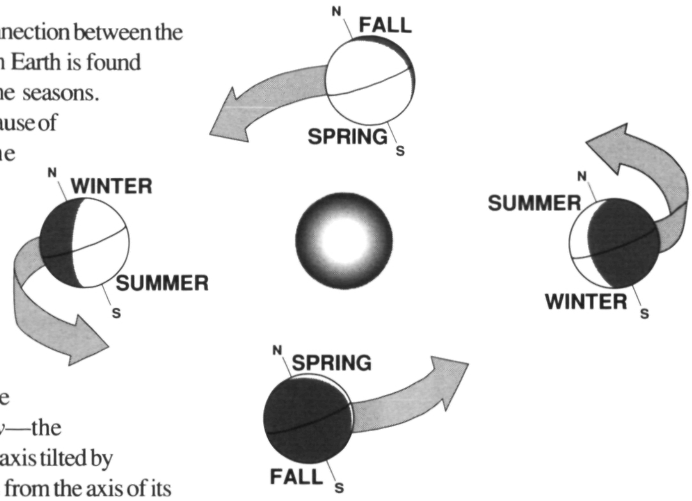
The complex structure of the solar corona seen in X-ray. (Yokoh satellite, a joint Japan-U.S. mission/NASA)

4c Living with a Star

The Earth receives only about one-billionth of the total energy radiated by the Sun, but this is enough to sustain the great diversity of life on our planet. The circulation of our atmosphere, the currents of the oceans, the photosynthesis at the base of our food chain—all are driven by energy from the Sun. Even the energy used by humans, with the exception of nuclear and geothermal energy, all can be traced back to the Sun. The flow of rivers for hydroelectric power, for example, is driven by the solar heat that causes evaporation and rainfall. Fossil fuels, like coal, oil, and gas, are the remains of organic life that depended on photosynthesis.

The Seasons

The most basic connection between the Sun and climate on Earth is found in the pattern of the seasons. Seasons occur because of variations in the amount of sunlight received in different regions of the globe at different times of year. The direct cause of the seasons is the Earth's *obliquity*—the Earth rotates on an axis tilted by about 23.5 degrees from the axis of its orbit around the Sun. As the Earth orbits the Sun its axis remains pointed in the same direction in space so that the northern and southern hemispheres alternately face toward the Sun. Thus, seasons are opposite in the two hemispheres: winter occurs in the north when summer occurs in the south, and vice versa.

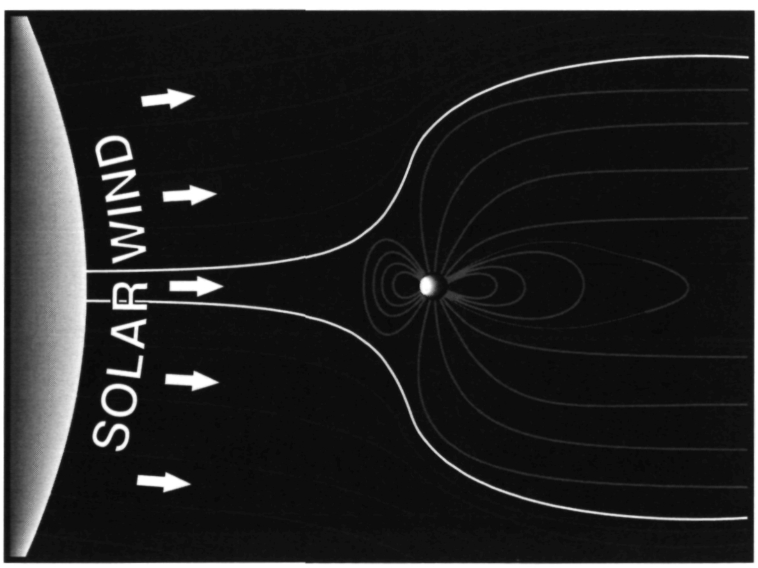


Solar Activity

The total energy output of the Sun is nearly constant. This is fortunate, as any significant variability would have devastating consequences for the Earth. A few solar phenomena vary, however, in what we call *solar activity*. The most obvious manifestation of solar activity is the *sunspot cycle*.

The total number of sunspots on the Sun at any one time varies in an approximately 11-year cycle. Because sunspots are regions of intense magnetic fields, many other solar phenomena are connected with them. Solar flares, for example, occur near sunspots and therefore are more common during solar maximum (i.e., when the sunspot number is high).

Sunspots have been observed regularly since Galileo first noticed them through his telescope. The smallest ones can barely be seen even with professional solar telescopes, while the largest can be seen through protective filters with the unaided eye. Ancient Chinese records contain many sightings of sunspots. Individual sunspots last no more than a few weeks, but new ones are constantly forming as old ones disappear.



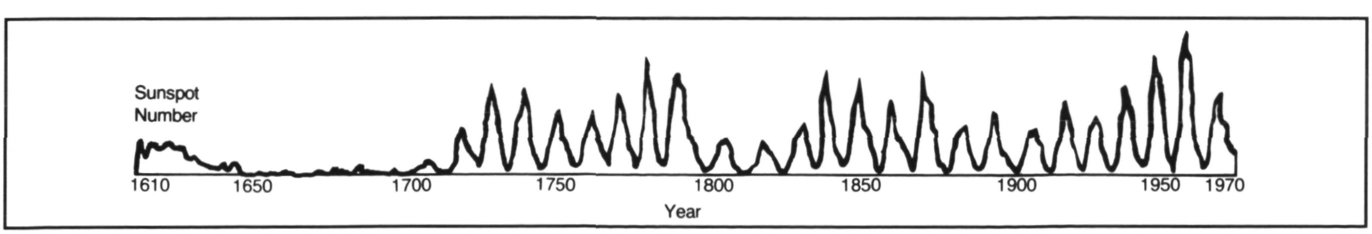
The solar wind interacts with the Earth's magnetic field.

Sun-Earth Relationships

Solar activity affects the Earth in many ways. Particles streaming out in the solar wind can become trapped in the Earth's magnetic field. These particles, along with others from the Earth's *ionosphere*, can collide with atoms in the Earth's atmosphere producing the magnificent, colorful light of the *aurora borealis* (or *aurora australis* in the southern hemisphere). During periods of intense solar activity, the aurorae extend farther from the poles, radio communications can be disrupted, and power surges can occur in electrical transmission lines.

Solar activity also can cause problems for spacecraft and astronauts. Intense activity causes the outer atmosphere of the Earth to heat and expand. This, in turn, can cause extra drag on satellites in low orbits, leading them to fall back toward the Earth. Following strong solar flares, large numbers of energetic particles, called *solar cosmic rays,* stream out from the Sun. Without special protection, such flares could prove fatal to astronauts in space.

Solar activity is a suspect in many climate perturbations, but neither the precise effects nor the mechanisms that might connect solar activity and climate are well understood. As we struggle to understand how human activity is affecting our planet, it is critical that we better understand the relationship between the Earth and the Sun so that we can clearly distinguish human-induced effects.

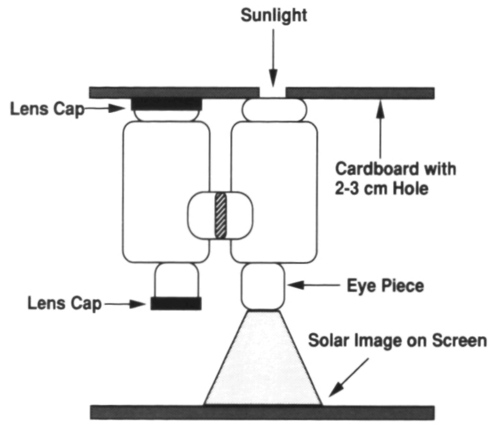


Sunspot numbers reveal the variability of solar activity.

4d For the Classroom

WARNING

NEVER OBSERVE THE SUN DIRECTLY WITH THE UNAIDED EYE OR THROUGH AN OPTICAL INSTRUMENT NOT DESIGNED FOR THAT PURPOSE!! PERMANENT EYE DAMAGE OR BLINDNESS CAN RESULT.



Activity 1: Safe Observing of the Sun

Materials: Binoculars or a small refracting telescope; tripod or other mounting system to hold optics steady; large piece of cardboard with an approximately 2-3 cm circular hole cut in center.

Background: Projection of a solar image, a technique that dates back to the 1600s, and is still used today at many major observatories for viewing the Sun. With a suitably large projected image, students can easily observe sunspots and other solar features. (Note: If you have a small telescope available, it is possible to directly observe sunspots with protective filters. Safe filters are available from most astronomical supply companies.)

Procedure:

(i) Cover one side of the binoculars completely; on the other side, tape the cardboard with the circular hole over the non-eyepiece end. If using a telescope, just place the cardboard over the end. The cardboard should be large enough to cast a wide shadow so that the solar image will be easy to see.

NEVER LOOK AT THE SUN THROUGH THE EYEPIECE.

(ii) Point the binoculars or telescope at the Sun by adjusting it until its shadow is minimized and sunlight comes through the eyepiece.

The cardboard-covered end should be toward the Sun, so that the image of the Sun projects out of the eyepiece. Use a tripod or other mounting system to hold the optics steady. (Mounting adapters are available at camera or optical stores.)

(iii) Use a white piece of paper or cardboard as a screen. Hold it about 30-40 cm behind the eyepiece, perpendicular to the light path. Slowly move it backwards until the Sun's edge, or *limb,* forms a sharp circle. The projected image is then in *focus.* Sunspots will appear as small, black dots that "jiggle" (due to turbulence in Earth's atmosphere) on the solar disk. A large sunspot will have a faint, grey border called the *penumbra,* while its dark center is called the *umbra.* Spots frequently appear in pairs or in groups, forming an *active region.*

(iv) Trace the limb of the Sun, and the positions of the sunspots on the screen with a pencil.

(v) Repeat the observations several times over a period of at least a week. You will see the number of sunspots varying from day to day. Also, the Sun rotates about once every 27 days; if you make observations at the same time each day, you will be able to observe groups of sunspots moving across the solar disk as the Sun rotates. (As the Sun moves across our sky, its north-south orientation rotates. If you do not observe at the same time each day, you will have to account for this effect in order to see the solar rotation.)

Activity 2: The Sunspot Cycle

The number and location of sunspots on the Sun changes with time. In general, the number of sunspots slowly increases for about 5 to 6 years, then decreases again, so that the total *sunspot cycle* averages about 11 years in length. During one school year, you will not be able to detect the sunspot cycle from your own observations. However, we have provided a chart listing the average yearly sunspot index for a period of about 40 years. (Note: the *sunspot index* is not just a simple count of sunspots; rather, each *group* of sunspots is counted as 10 individual spots, and this is added to the number of individual spots themselves.)

Ask students to make a graph with time (year) on the horizontal axis and sunspot number on the vertical axis. Notice differences in the length and characteristics of individual cycles. Use the graph to predict approximately when the next solar minimum and maximum will occur (answers: 1996 and 2001, respectively).

For Further Research

1. The sunspot cycle reveals the magnetic activity of the Sun, and is related to many other solar phenomena. Sunspot records go back only a few hundred years. Investigate how scientists are able to estimate solar activity even during times before we had written records of sunspot number.

2. Investigate connections between solar activity and climate. In particular, study the period of the "Little Ice Age" during the late 1600s and early 1700s.

3. Find out how much energy the Earth receives from the Sun. Compare with current world energy usage. Explore the feasibility of solar power as an energy source to replace fossil fuels.

Year	Sunspot Index	Year	Sunspot Index
1951	69.4	1972	68.9
1952	31.5	1973	38.0
1953	13.9	1974	34.5
1954	4.4	1975	15.5
1955	38.0	1976	12.6
1956	141.7	1977	27.5
1957	190.2	1978	92.5
1958	184.8	1979	155.4
1959	159.0	1980	154.6
1960	112.3	1981	140.4
1961	53.9	1982	115.9
1962	37.6	1983	66.6
1963	27.9	1984	45.9
1964	10.2	1985	17.9
1965	15.1	1986	13.4
1966	47.0	1987	29.4
1967	93.8	1988	100.2
1968	105.9	1989	148.0
1969	105.5	1990	142.8
1970	104.5	1991	149.0
1971	66.6		

5a Looking at Life from Space

The Earth today is rich with life. Its diversity is so great that we have not even completed a census. There may be 5 to 30 million species, yet we have named fewer than 2 million; fewer still have been studied in detail. Everything on which human survival depends is tied to this diversity of life, though we are still learning exactly how. Even the specific composition of our atmosphere is controlled by biological activity. Yet, in spite of our ignorance of the ecological roles played by many living organisms, human activity is driving species extinction at an ever-increasing rate.

The exploration of space offers us a new perspective from which to understand life. We see the Earth as a tiny and fragile oasis in the hostile environment of space. We develop a renewed appreciation for the beauty and value of life, and we wonder anew about the origins of life. How did such an amazing array of life begin and evolve on our planet? Has a similar process occurred on other planets, either in our own solar system or beyond? If so, might we someday establish contact with civilizations born around other stars? We are just beginning the search for answers to these fundamental questions.

Life: A Product of the Stars

The essential raw materials of life are the *biogenic elements* —hydrogen, carbon, nitrogen, oxygen, sulphur, and phosphorus—from which all living things are made. To find the origins of the biogenic elements, we must go all the way back to the *Big Bang*, the beginning of our universe some 10 to 20 billion years ago. Only the lightest elements, hydrogen and helium, were produced during the Big Bang. These remain, by far, the most common elements in the universe. Although hydrogen, an ingredient of water, is essential to life, other elements had to be created before life could exist.

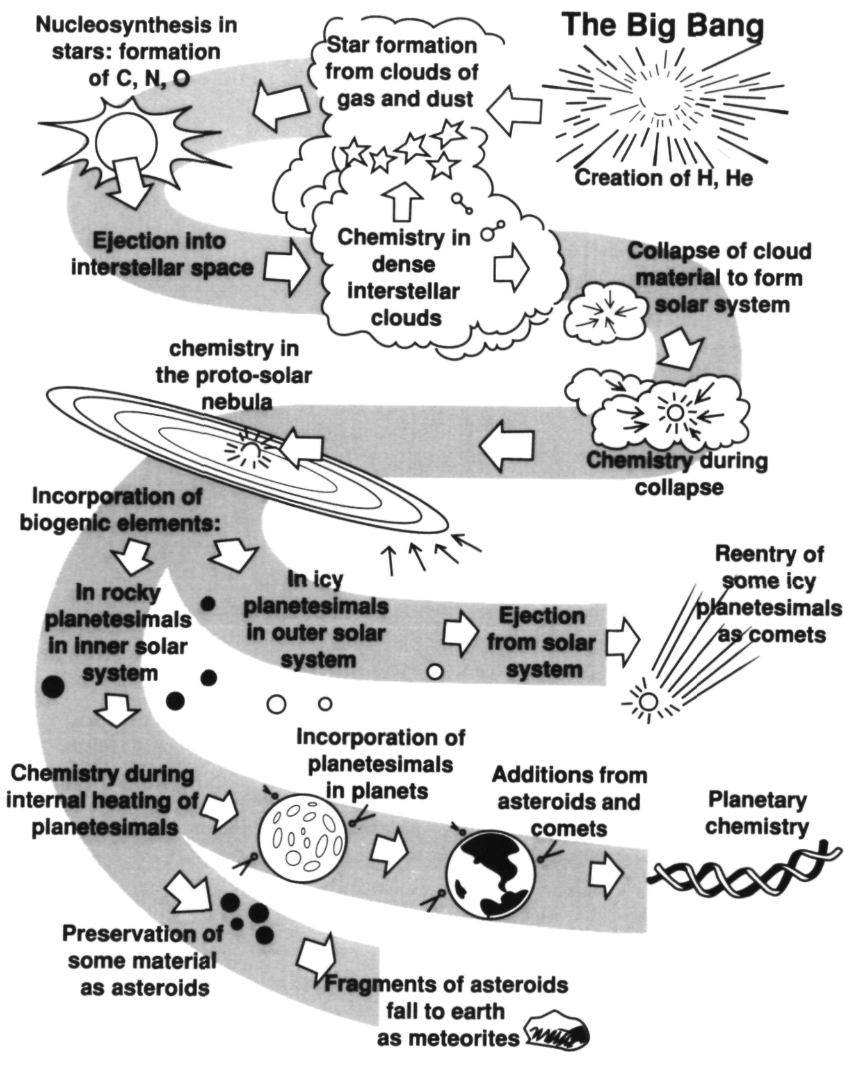
Carbon, nitrogen, oxygen, and all the other heavier elements were produced by stars. Stars are born when clouds of interstellar gas collapse under gravity, and live by fusing hydrogen into helium in their cores. If a star is sufficiently massive (i.e., a few times more massive than the Sun), it will burn the hydrogen in its core at a prodigious rate, and soon exhaust its supply. Gravity will then collapse its core to ever higher temperatures, allowing the star to fuse helium into carbon, carbon into oxygen, and so on. Through this process, called *nucleosynthesis,* the biogenic elements are formed.

The final death of a massive star occurs in a titanic explosion, called a *supernova,* during which its products are returned to interstellar space. There, they are recycled into future generations of stars. Our solar system was made from such recycled material. The Earth, with all its living organisms, is built from elements created inside massive stars that died before our solar system was born. Truly, we are products of the stars.

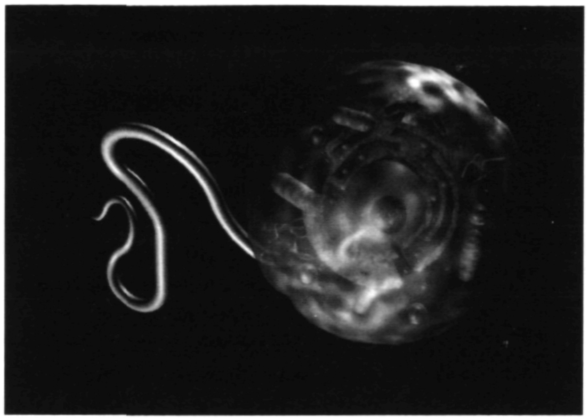
The Cosmic History of the Biogenic Elements

The cartoon below shows the cosmic history of the biogenic elements—the raw materials of life. Hydrogen and helium were created in the Big Bang. From clouds of these gases, the first generation of stars was formed. Nucleosynthesis in the cores of massive stars produces heavier elements like carbon (C), nitrogen (N), and oxygen (O). Stellar explosions and stellar winds recycle material back into space, including the newly formed elements. The formation of subsequent generations of stars is aided by the chemistry of interstellar clouds.

When our solar system formed about 4.6 billion years ago, the composition of the planets was shaped by chemistry in this solar nebula. Small chunks of rock—planetesimals—condensed from the gas and dust in the inner solar system and combined to form the inner planets, including Earth. A few chunks still remain, as asteroids. In the colder, outer solar system, icy planetesimals formed, and may have been the seeds for the giant planets. Some icy chunks were ejected to great distances from the Sun, where they reside as comets. Life began in the planetary chemistry on Earth. Occasionally, fragments of asteroids and comets collide with Earth, affecting the evolution of life (seen as the double helix structure of DNA).



5b The Origin of Life



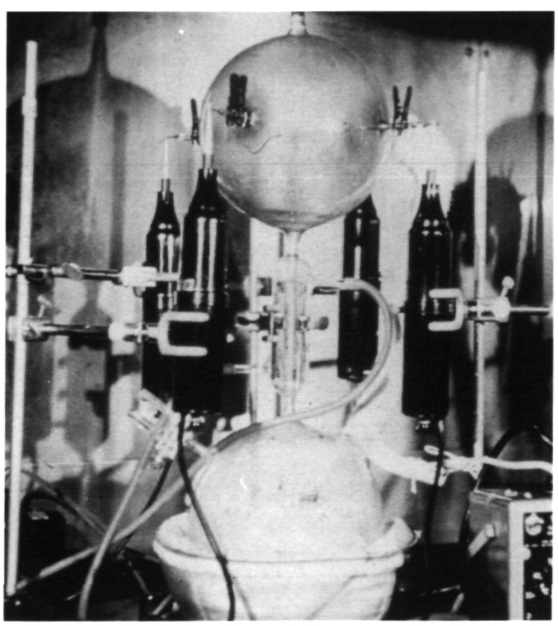
Artist's conception of a eukaryote, a single cell with complex structures, including a nucleus. All plants and animals are built from eukaryotic cells. (Courtesy of Andy Joyce)

All organisms on Earth are made from the same basic building blocks, yet we find an enormous variety of characteristics in the biological world. The instructions for building organisms are encoded in their *genes;* all living organisms use the molecule called *deoxyribonucleic acid,* or *DNA,* as their genetic material. How did this incredible system arise? Where did the raw materials—the building blocks—come from?

Chemical Evolution

The early Earth was very different from the Earth of today. The length of a day was much shorter. Tides were more extreme (because the Moon was closer). Oceans were shallower, and continents bore little resemblance to the ones we know. There was little or no free oxygen in the atmosphere. During the first few hundred million years, impacts by asteroid and comet fragments were relatively frequent, and the landscape was dotted by impact craters.

Although conditions would have been deadly to us, they were ideal for *organic chemistry.* Energy from lightning and ultraviolet radiation fueled chemical reactions, producing complex organic molecules. Additional organic material might have been brought to Earth by asteroids or comets. We do not know exactly how the first living cell came to exist, but it happened in this rich chemical environment, sometime within the first billion years of Earth's history.



A flask containing the chemicals of the Earth's early atmosphere, sparked by electricity to simulate lightning, forms a dark sludge of organic molecules. (Courtesy of Cyril Ponnamperuma)

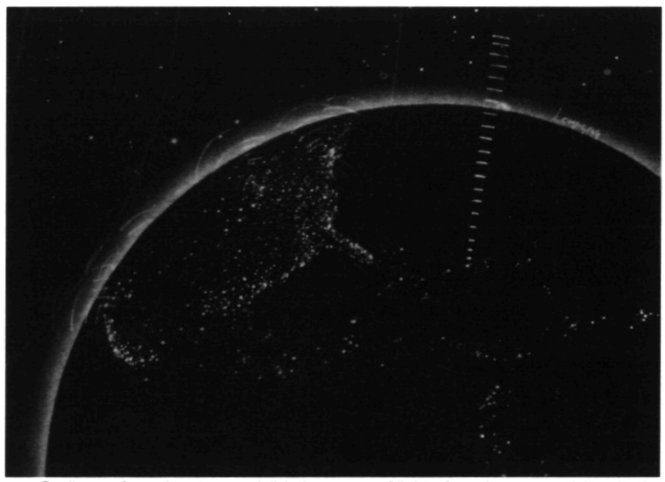
The oldest known fossils date back about 3.5 billion years. Evidence for earlier life may have been erased by geological processes. In fact, life might have arisen several times, only to be extinguished by the frequent major asteroid or comet impacts on the early Earth. Once the first successful organism took hold, however, it would have quickly spread on the planet. All living organisms today share many common features; perhaps all are descended from that single ancestor.

Biological Evolution

The earliest living cells must have been very simple organisms; probably bacteria-like, single-celled *prokaryotes.* The great diversity of life arose as organisms evolved and passed on new traits. Organisms are constantly changing from one generation to the next through *mutations*—changes in the genetic material (DNA)—or through the shuffling of existing genes. Existing characteristics can also be combined through the *symbiotic* merging of organisms. Most genetic changes have little effect, and some are detrimental or fatal. Occasionally, however, a genetic change makes an organism more capable of living and multiplying in its environment; when the organism reproduces, the new trait is passed on to its descendents. This process, in which beneficial genetic changes are selectively passed on from one generation to the next, is called natur*al selection.*

Evolution is a slow process. It took some 2 billion years for life to evolve from the earliest prokaryotes into the more complex *eukaryotes*— cells which possess a nucleus. Nearly a billion years more passed before multi-celled organisms arose, and it is only in the last 500 million years that higher plants and animals have evolved.

Evolution does not always progress at a steady pace. The fossil record reveals several episodes of *mass extinctions,* possibly triggered by meteorite impacts. One of these, about 65 million years ago, ended the age of the dinosaurs, leading to the age of the mammals and, ultimately, humans.



Outlines of continents are visible because of lights from human activity. In the part of the spectrum where radio and television are broadcast, the Earth is the brightest object in the solar system. (Courtesy of Jon Lomberg)

Intelligence and Technology

Humanity's dominance of our planet demonstrates the evolutionary impact of intelligence, though we have not yet proven that intelligence is sufficient to ensure our survival. Still, it took over four billion years from the time the Earth formed until intelligence evolved. Was intelligence inevitable? What about technology? Humans have walked the Earth for more than 2 million years, but only in the past 100 years have we developed technology that could allow us to communicate with other worlds. Today, we outshine the Sun in certain radio and television wavelengths, effectively announcing our presence as those signals spread from the Earth at the speed of light. Perhaps someone, somewhere, is listening.

5c Life Beyond Earth

There is no reason to believe that the chemical processes that led to life on Earth could not have occurred elsewhere. Indeed, organic molecules are ubiquitous in the universe, found on planets and moons in our solar system, asteroids and comets, and even in the interstellar clouds from which stars are born.

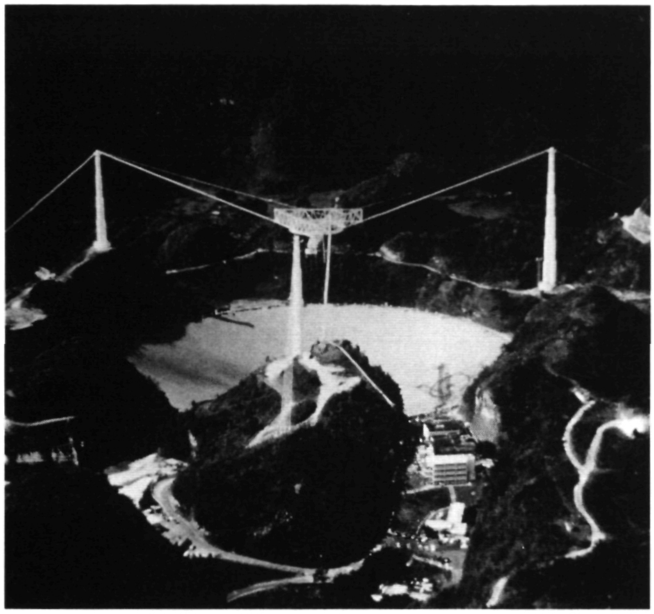
Life in the Solar System

Science fiction is filled with tales of alien civilizations in places as nearby as Mars. Alas, planetary probes have found no evidence of alien intelligence in our solar system. But life on Earth existed only as single-celled, microscopic organisms for most of its history. Might we yet discover life, past or present, elsewhere in our own solar system?

The atmospheres of the giant planets (Jupiter, Saturn, Uranus, Neptune) contain many organic molecules, but their turbulence makes them unlikely candidates for the development of life. Organic chemicals also are found on Saturn's moon Titan, but its surface temperature is too cold for liquid water. The large icy moons in the outer solar system, like Jupiter's moons Europa, Ganymede, and Callisto, and Neptune's moon Triton are frozen, airless worlds that could not support life on their surfaces, but may have complex interior chemistry. Even more intriguing, Europa may hide a giant ocean of liquid water beneath its barren crust.

The Search for Extraterrestrial Intelligence (SETI)

The vast distances between stars put interstellar travel far beyond our current technology. Fortunately, we can communicate across the stars at the speed of light using radio. The *Search for Extraterrestrial Intelligence* (SETI) is an activity to listen, using large radio telescopes for a signal broadcast by a distant civilization. Small-scale SETI efforts have been tried by individual researchers since the 1960s. A more formal search, with radio telescopes tuned to listen simultaneously to tens of millions of frequencies as they scan the skies, is set to begin as an international effort in 1992. Success cannot be guaranteed. Even if a signal has been broadcast to us, a radio telescope would have to be pointed to the right place at the right time. Nevertheless, the impact of detecting a civilization that evolved around another star would be tremendous. At last, we would know the answer to the question: are we alone?



Built in a natural valley in Puerto Rico, the Arecibo radio telescope is the world's largest, and a key facility in the SETI project. (National Science Foundation)

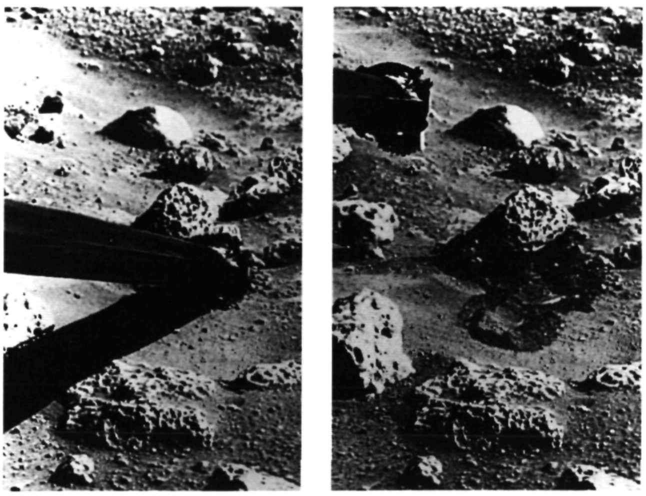
Venus and Mars

Venus, Earth, and Mars all had similar beginnings, starting with similar compositions and nearly identical atmospheres. If life evolved quickly on the early Earth, perhaps it did likewise on Venus or Mars. Today, a runaway greenhouse effect bakes Venus at 450 ° C, far too hot for life as we know it.

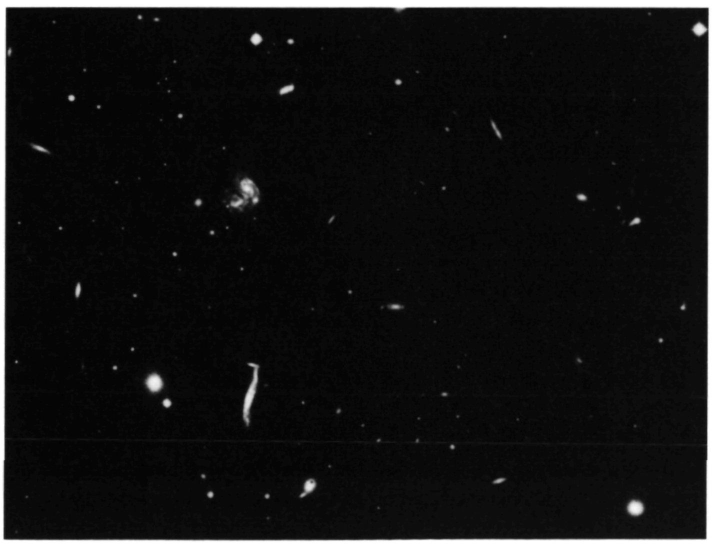
Mars is a better candidate. Pictures of Mars reveal ancient river beds, suggesting that Mars once had plentiful liquid water and warmer temperatures. Perhaps life evolved on Mars, only to be extinguished as the planet cooled. If so, fossil hunting on Mars could be an exciting business. Or perhaps, if life evolved, it adapted and still survives in isolated areas of the planet.

Life in the Universe

The Sun is just one of more than a hundred billion stars in the Milky Way, and our Galaxy is just one of some ten billion galaxies in the universe. The vast majority of stars are similar to the Sun in size and brightness, and many are as old, or older. Although we have not yet directly detected planets around any other star, it is likely that many stars are orbited by a host of planets. Among the most intriguing of all questions are whether any of these planets support life and whether any of that life has evolved to develop a civilization.



Two Viking spacecraft landed on Mars in 1976. Here, we see a small rock pushed aside by the robotic arm of Viking 2. The spacecraft found no conclusive evidence for life, but sampled only two tiny patches of the planet.



A distant cluster of galaxies, each typically with a hundred billion or more stars. (Hale Observatory)

5d For the Classroom

Activity 1:
Journey to a New World

The following activity is a writing project that can be modified or adapted for almost any grade level. It asks students to work in groups to write a science fiction story about a journey to another star system, the planets and life that they find, and their return to Earth. The activity asks students to work in groups, with each student writing a chapter for the story; this can be an effective exercise in group interaction. In addition, the activity requires students to combine their scientific understanding with social and environmental issues. If you are working with the entire poster set, this activity makes an excellent "summary" of many of the concepts learned on the first five posters.

Story Outline: Students should be divided into groups of four or more. Each group is asked to write a story of the same basic structure, with each student writing a chapter. The stories should all have certain basic features:

- The trip is to another star system. Students can invent its characteristics, but should be scientifically reasonable. For example: A life bearing planet must be neither too close nor too far from the star; the star should not be much bigger than the Sun, since massive stars live short lives—too short to give biological life time to evolve; etc.

- Students should assume their spacecraft is capable of traveling at speeds close to the speed of light; in that case, effects of Einstein's theory of relativity come into play. You need not know much about relativity, except that if they travel very close to the speed of light only a short amount of time will pass on their starship while a much longer time will pass on Earth. For example, they could make a trip to a star 20 light-years distant in, say, 6 months of travel time each way. On Earth, however, more than 40 years (20 for each direction) would have passed while they were away. Similarly, the starship might take only months for a round trip to a star 100 light-years distant, but more than 200 years would have passed on Earth when the students return. And so on.

- Students should find life on at least one of the planets in the star system, and make a careful study of the planet's global ecology. If they find intelligent life, or a civilization, they should describe its social and political structures. Also, they should decide whether or not to make contact with the civilization, explaining their choice. If they do make contact, they should describe what happens.

Suggested Chapters:: For groups of four students, each student should write one of the following chapters:

Chapter 1: Preparation and Journey. A description of the preparations for an interstellar trip and of the journey itself. For example: what star system does the group plan to explore, how far away is it, and why did they choose it? What must they take for supplies? What is their spacecraft like? How many crew members, and what do they do?

Chapter 2: Arrival and Exploration. A description of the star and its planetary system. For example: Does the star have activity like our Sun? What are the planets like? Are they divided into inner planets and giant planets like our solar system? Which planet(s) have life? How do they detect it?

Chapter 3: Planetary Ecology. A description of the global ecology of the planet(s) with life, and of some of the major life-forms. Are any intelligent?

Chapter 4: Return to Earth. Only months may have passed on their spaceship, while many years will have passed on Earth. How much time has passed, and what do they find when their group returns to Earth? How do they feel about the changes, and what will they do with the rest of their lives?

If a group has more than four students, chapter 3 can be broken into more chapters. For example: one chapter on the global ecology; another on the social structures of the civilization; another on contact, or a decision not to make contact, with the civilization; etc.

Further Suggestions:

- Be sure that each group works together so that the story flows smoothly, without inconsistencies, from one chapter to the next. It is a good idea to ask each group to begin by outlining their concept, forming a consensus on the major features of their story. It can be very useful to have some adult guidance for each group; a parent volunteer might sit with each group, or the teacher can circulate among the groups.

- Let students be as creative as they wish, but make sure they are scientifically reasonable. If they create a concept that seems highly unlikely, ask them to change it. There is plenty of room for creativity within conventional scientific understanding, and the point of this activity is to learn more about the new scientific perspectives from space.

- The chapter on the return to Earth can be used to raise numerous social issues. For example: What environmental changes have happened on our planet? What political or social changes? What has happened to their families and friends?

- Younger children can write stories that are fairly short and simple. Older students can be asked to do background research to ensure the scientific validity of their stories, and can produce stories that are quite long and detailed.

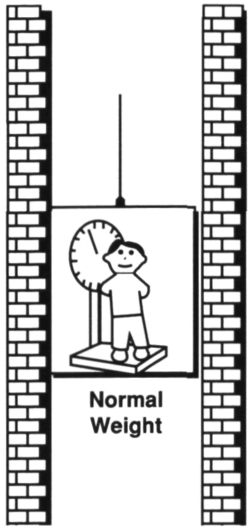
- The writing activity can be supplemented with artwork. For example: students might draw illustrations for their story; make models of the planetary system, or even of the interior structure of the planets; make models to represent the life-forms they discover; etc.

Activity 2:
Soil Cultures

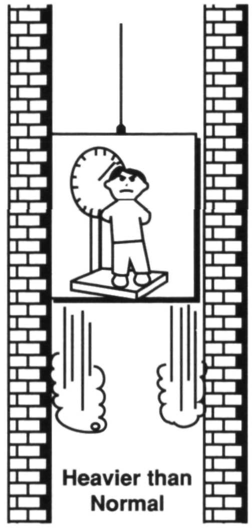
Procedure: Take some soil from the yard, and place a small amount into each of four small jars. Add sugar water (about one teaspoon per cup) to two of the jars. Then, sterilize one jar with sugar and one without, by standing the jars in boiling water for a half-hour. DO NOT SEAL THE JARS WHILE BOILING. Wait for the sterilized jars to cool, then cover all four jars. You now have four soil samples: (1) sterile, (2) sterile with sugar, (3) not sterile, and (4) not sterile with sugar. After one week, observe the differences between the four jars. Open them, take small samples, add a little water and look at the samples with a magnifying glass.

Discussion:: Explain your results. Suppose you were given a soil sample from another planet, like Mars. How would you determine if there was anything alive in the sample?

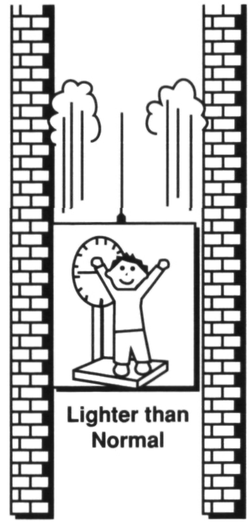
6a Understanding Gravity



Elevator stationary, or moving at constant speed.



Elevator accelerating upward.



Elevator accelerating downward.

Gravity is the force that governs motion throughout the universe. It holds us to the ground, keeps the Moon in orbit around the Earth, and the Earth in orbit of the Sun. Even the great swirl of the Milky Way, rotating once in a quarter billion years, is the result of gravity. Yet gravity remained a mystery for most of history. Only in the past 300 years have we come to understand the nature and role of gravity.

Newton's Law of Gravity

The nature of gravitational force was first described by Sir Isaac Newton, slightly more than 300 years ago. Newton's *Law of Universal Gravitation* is summarized by three simple statements: (1) Every mass attracts every other mass through the force we call gravity. (2) The force of attraction between any two objects is *directly proportional* to the product of their masses. If, for example, we double the mass of one object, then we double the force. (3) The force of attraction between the objects goes down (i.e., it is *inversely proportional*) with the square of the distance between their centers. Thus, if we double the distance, the force of gravity weakens by a factor of 2^2, or four.

The Acceleration of Gravity

A mass, like the Earth, creates a *gravitational field* that acts to attract other objects according to the Law of Universal Gravitation. Thus, when a rock is dropped it is attracted toward the center of the Earth by gravity, accelerating downward until it is stopped by the ground. The acceleration caused by gravity, alone, near the surface of the Earth is called "one gee" (1g).

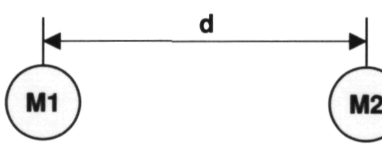
Gravity, Mass, and Weight

Mass and weight are not the same thing. The mass of a particular object is the same wherever it is located, but its weight can vary. Imagine standing on a scale in an elevator. When the elevator is stationary, the scale reads your "normal" weight (on Earth). When the elevator is *accelerating* upward, the floor exerts an additional force on you. You feel heavier, and the scale verifies your increased weight. When the elevator *accelerates* downward, the floor (and scale) are dropping away, so your weight is decreased. (Note that you *will experience the sensation* of changing weight only while the elevator is *accelerating,* not while it is moving at a constant speed.)

Mathematically, Newton's *Law of Universal Gravitation* is:

$$F_g = G\frac{M_1 M_2}{d^2}$$

where F_g is the force of gravity, M_1 and M_2 are the masses of the two attracting objects, and d is the distance between their *centers.* G, the *gravitational constant,* is measured by experiment.
In SI units, $G = 6.67 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$.



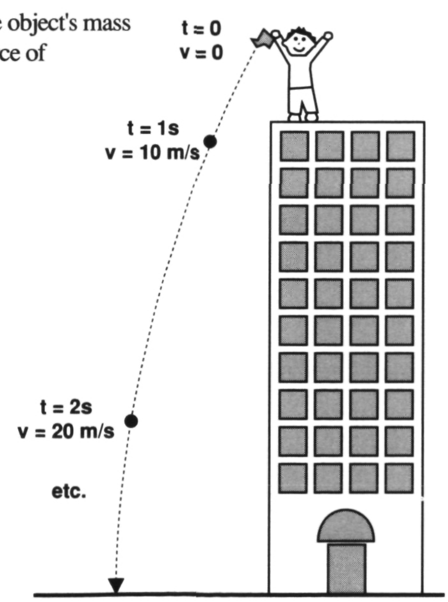
Newton's *second law of motion* states that the force on any object is equal to the product of the object's mass and acceleration. Thus, we can calculate the acceleration of a dropped rock by equating the force of gravity (F_g) with the product of the rock's mass (M_{rock}) and acceleration (a_{rock}):

$$F_g = G\frac{M_{Earth} M_{rock}}{d^2} = M_{rock}\, a_{rock}$$

Solving for the acceleration:

$$a_{rock} = G\frac{M_{Earth}}{d^2}$$

d is the distance between the center of the rock and the center of the Earth which, since the rock is very near the Earth's surface, is just the radius of the Earth (6.4×10^6 m). The mass of the Earth is 6.0×10^{24} kg. You can do the multiplication to verify that 1 g, the acceleration of gravity near the surface of the Earth, is about 10 meters per second per second. Thus, a dropped object would be falling at a speed of 10 m/s after one second, 20 m/s after two seconds, and so on until it hits the ground (neglecting air resistance which will slow the acceleration). Notice that the acceleration of the rock (a_{rock}) does not depend on the mass of the rock (M_{rock}). Thus, all objects fall toward the ground with the same acceleration (neglecting air resistance).

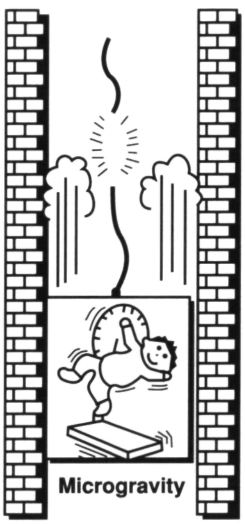


6b Space and Microgravity

In orbiting laboratories like the Space Shuttle, or in space stations like Skylab, Mir, or Freedom, astronauts float freely, spinning or tumbling as they please. Their great freedom of motion comes about because, while orbiting the Earth, they are (very nearly) weightless. Yet, the Earth's gravity does not disappear in space. The Moon, for example, is held in orbit by the Earth's gravity, even though it lies far beyond the low-Earth orbits of the Space Shuttle and space stations. In fact, the acceleration of gravity is scarcely any different in low-Earth orbit (about 10 percent less) than on the ground. Why, then, do orbiting laboratories offer conditions of near weightlessness, or *microgravity?*

Free-fall and Microgravity

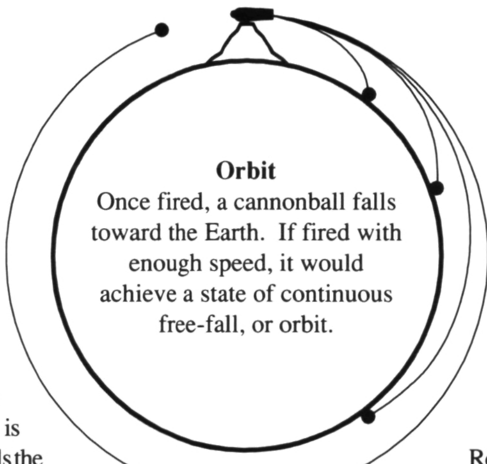
The condition of microgravity comes about whenever an object is in *free-fall;* that is, when it is accelerating with exactly the acceleration due to gravity. (Under most free-fall conditions, the acceleration will be very close to, but not exactly equal to the acceleration of gravity; thus, it is more accurate to speak of "near weightless-ness.") Imagine standing on a scale in an elevator when the support cables break. You, your scale, and the elevator begin falling toward the bottom of the shaft, all at the same rate (discounting air and mechanical friction). Thus, the scale registers nothing—you feel weightless. You feel just like the astronauts in orbit.



Elevator in free-fall.

Orbit

Orbiting laboratories offer near weightless-ness because they are in a state of continuous free-fall. We can understand this with a *thought experiment* first used by Newton: Imagine placing a cannon on the top of a very tall mountain, aimed to fire cannonballs parallel to the ground. The cannonballs are initially propelled straight outward by the force of the explosion of the cannon's gunpowder charge. If there were no other forces involved, the cannonball would travel in a straight line away from Earth, forever. But because the cannon-ball is fired from the Earth, a second force is acting, gravity, that pulls the cannonball toward the center of the Earth. The net result is the flight of the cannonball in an arc, ending when it crashes to the ground.



Orbit
Once fired, a cannonball falls toward the Earth. If fired with enough speed, it would achieve a state of continuous free-fall, or orbit.

Now suppose the cannon were loaded with more gunpowder for each successive cannonball. Each cannonball would follow a longer arc than the previous one. Eventually, we could imagine a cannonball propelled so fast that it would actually "fall around" the Earth, returning to its starting point, to go around again. This is what we call continuous free-fall or *orbit.* In the absence of friction (e.g., from the upper atmosphere), the cannonball would orbit the Earth indefinitely.

Note that orbits need not be circular. If the cannonball is fired at an angle, it could go into an *elliptical* orbit around the Earth. If it is fired sufficiently fast, achieving *escape velocity,* the cannonball would never return to the Earth.

The Concept of Microgravity

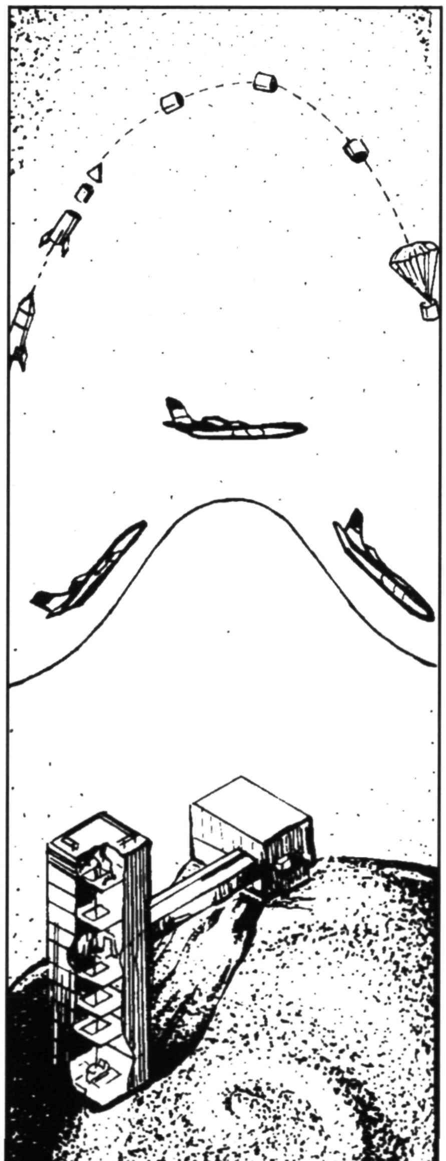
Let go of a rock held above the ground, and it will fall to Earth. Let go of a rock inside an orbiting spacecraft, and it will appear to remain stationary because you, the rock, and the spacecraft all are in continuous free-fall together.

In fact, the rock will not be completely weightless. In low-Earth orbit, a variety of small forces produce slight accelerations. These include drag from the upper atmo-sphere, motions within the spacecraft, and the curvature of the spacecraft's orbit. Thus, conditions in the spacecraft are nearly, but not quite, weightless. We call these conditions *microgravity,* since they arise from accelera-tions very small compared to the acceleration of gravity on Earth. (The prefix *micro* is derived from the Greek word *mikros,* meaning "small.")

Microgravity on Earth

The instant you jump off a diving board, or bounce upward from a trampoline, you are in free-fall. Thus, for a very short time you are experiencing the sensations of microgravity, allowing you to spin, tumble, or twist like astronauts in space.

Researchers can create a few seconds of microgravity by conducting experiments falling from tall *drop towers,* or a few minutes on *sounding rockets* that do not achieve orbit. Astronauts can train for the space environment with about 30 seconds of microgravity in specially designed airplanes that follow a parabolic, free-fall trajectory.



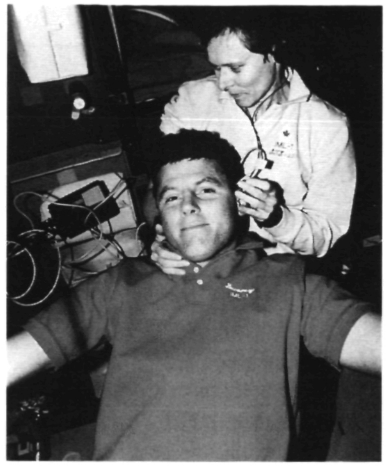
Drop towers, airplanes on parabolic trajectories, and sounding rockets offer short periods of microgravity.

6c Microgravity Environment

Orbiting laboratories allow us to study physical, chemical, and biological processes in microgravity. In this way, we gain new insights into phenomena usually obscured by the effects of gravity.

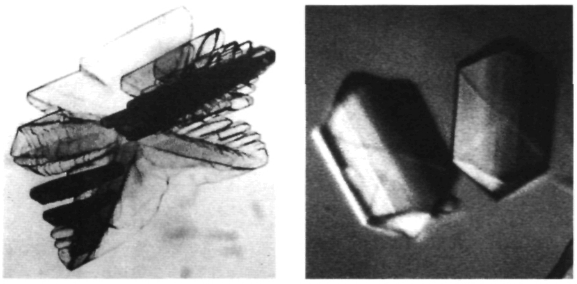
Human Physiology

Long space voyages to distant worlds like Mars or beyond may require humans to live in microgravity for many months or even years. Unfortunately, astronauts who have spent long periods of time in space suffer many physiological problems. Bones lose calcium, becoming brittle, and muscles weaken. The heart, after not having to pump against gravity, becomes smaller and weaker, and microgravity changes the response of the body's vestibular (balance) system. Further research to better understand the effects of microgravity on human physiology is critical before we can undertake long voyages to the planets.



Biotechnology

We can better understand the activity of proteins and other organic molecules in living cells by studying their crystalline structures—that is, the precise arrangement of their atoms. To do this, we grow crystals of the molecules from liquid protein solutions. On Earth, gravity can cause *sedimentation,* and *buoyancy-driven* fluid flows which may distort the shape of a growing crystal.



Crystals of a protein grown on Earth (left) may have odd shapes that interfere with analysis. At right, crystals of the same protein grown in space.

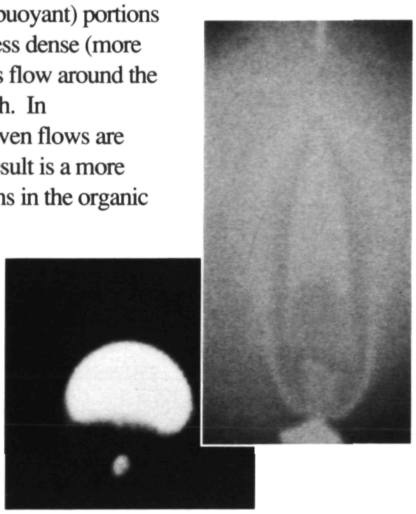
Sedimentation is the process in which, under normal gravity, crystals settle to the bottom of the liquid. This can interfere with the growth of the parts of the crystals touching the walls of the container. In space there is no up and down, and therefore no sedimentation.

Buoyancy-driven flow occurs on Earth because of weight differences between portions of fluid with different densities: gravity causes denser (less buoyant) portions of the liquid to sink while less dense (more buoyant) portions rise. This flow around the crystal can disturb its growth. In microgravity, buoyancy-driven flows are virtually eliminated. The result is a more perfect arrangement of atoms in the organic crystal.

Combustion

The familiar upward arc of a candle flame is another artifact of gravity. *Combustion* — the release of chemical energy through burning—heats the surrounding air. High temperatures cause the heated products to glow, producing a flame. On Earth, the heat causes buoyancy-driven flow: the warm air rises, generating air currents as cooler, heavier air sinks to replace it.

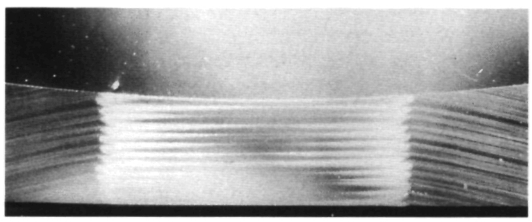
In space, the air around a candle flame will not move via buoyancy-driven flows. We can study the process of combustion without the interfering effects of gravity.



Compare the spherical shape of a flame in microgravity (left) with that of a flame on Earth (right).

Materials Science

The goal of *microgravity materials science* is to make the best use of the space environment to understand the physical processes and phenomena which govern the formation, structure, and properties of all types of materials. Examples of materials that are studied include metals, glasses, ceramics, polymers (e.g., plastics), semiconductors (used in many electronic devices), and combinations called composites.



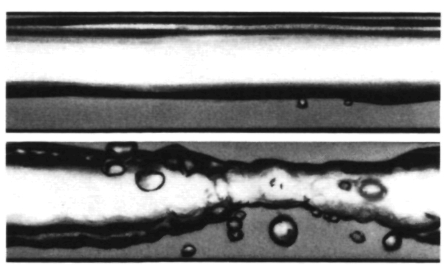
A slice from a crystal grown in space, starting from a "seed" crystal grown on Earth. The lower part is the seed (1 cm diameter), with defects caused by buoyancy-driven flow. The upper part grew in space.

The fundamental connection between the formation of a material and its properties can be studied by growing and analyzing crystals. One method of crystal growth involves carefully controlling the freezing of a liquid. The starting material is melted in a tube with one end placed in a hot furnace and the other end in a cooler area. Often, a "seed" (small, high quality crystal) is placed at the cooler end to help initiate crystal growth. The tube is slowly moved from the hot furnace to the cooler area; the crystal "grows" as the liquid freezes. Since part of the liquid is hotter than other parts, buoyancy-driven flows will occur on Earth. In space, buoyancy-driven flows are virtually eliminated; crystals grown there may have greatly improved properties compared with those produced on Earth.

Fluid Phenomena

When air and water are mixed in a container on Earth, gravity pulls the heavier water to the bottom while the air floats to the top. This is true even in pipes where the air is mixed in with moving water.

In space, a mixture of air and water in a pipe behaves very differently. The air can form big bubbles—called *slugs*—preventing a smooth and continuous flow of the water. Since the flow of liquids and gases (at the same time) is very important to the safe operation of equipment in space, an understanding of these processes is critical.



Air rises up above flowing water on Earth (top); in space, air bubbles remain mixed with the liquid (bottom).

6d For the Classroom

Activity 1: Free-Fall Demonstration

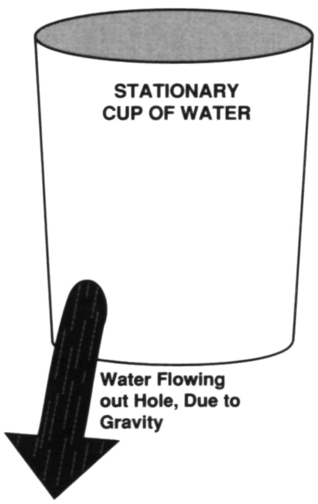
Concept: If we put a hole in a cup of water, gravity will cause the water to leak out. In free-fall, however, the cup and the water will be in a microgravity environment, and will not leak.

Materials: A small Styrofoam or paper cup. Optional: a video camera and monitor.

Procedure: (1) Use a sharp pencil to punch a small hole in the side of the cup, near its bottom. (2) Cover the hole with your thumb while filling it at least two-thirds full of water. (3) Remove your thumb, and note the rate of water flow from the hole. (4) Refill the cup with your thumb over the hole. (5) Raise the cup over your head and carefully drop it so that its bottom points toward the ground as it falls; closely observe what happens (optional: videotape the fall and replay it in slow motion).

Discussion: Before beginning, ask your students to predict the results. Discuss the observations. Are they surprised? What would happen if you performed this experiment in an orbiting laboratory?

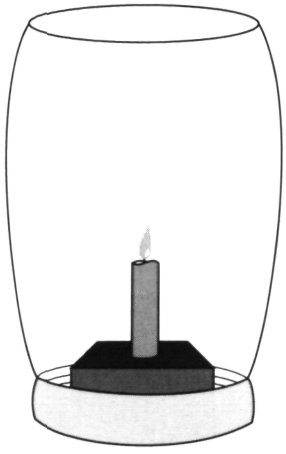
Activity 1 Diagram



Activity 2: Candle Drop

Concept: A candle flame on Earth is shaped and fed by buoyancy-driven flow (see panel 6c). Without buoyancy-driven flow, the flame will be quite different. If new oxygen cannot move rapidly enough to feed the flame, the flame temperature will diminish, reducing the heat fed to the candle and the vaporization of the candle wax. If the flame temperature falls below critical values (that depend on the type of candle), the flame will be extinguished.

Activity 2 Diagram



BE SURE FLAME DOES NOT TOUCH JAR

KEEP ALL FLAMMABLE MATERIALS AWAY FROM THE AREA WHERE YOU CONDUCT THIS EXPERIMENT

Materials: A clear plastic jar with lid (half-liter capacity or larger); wood block; birthday cake candles; matches; screws; drill and bit. Optional: a video camera and monitor.

Procedure: (1) Cut the wood block to fit inside the lid of the plastic jar, and attach it with screws from the top. (2) Drill a hole in the center of the block to serve as a candle holder; insert a candle. (3) Darken the room. With the lid on the bottom, light the candle and quickly screw the plastic jar over it. (4) Observe the shape, brightness and color of the candle flame (if the oxygen inside the jar is depleted before the observations can be completed, remove the lid, relight the candle and reseal the jar). (5) Raise the jar over your head and drop it with the lit candle. Be sure someone catches the falling jar. (6) As the candle drops, observe the shape, brightness, and color of the candle flame. (7) Since the action takes place quickly, you should observe several drops. (Optional: videotape the experiment; use the freeze frame or pause to examine the candle flame during free-fall.)

Discussion Questions: Ask students to compare the candle flame shape and brightness during free-fall with that at rest. Do students agree on what they saw? Compare their observations from drop to drop. If the flame went out, discuss why. Use the results to help your students discuss the impact of buoyancy-driven flow not only on the candle flame, but in other processes that are familiar on Earth.

Further Research: If a balcony is available, you can drop the jar a greater distance. Use a large box filled with Styrofoam or other packing material to catch the falling jar so that it will not break and create a fire hazard. Does the candle continue to burn through the entire drop?

Activity 3: Buoyancy-Driven Fluid Flow

Concept: In the presence of gravity, crystal growth is affected by buoyancy-driven flow as less dense fluid rises and more dense fluid sinks. The density differences arise because, as the solution deposits material onto the growing crystal surface, the density of the solution is reduced. This activity makes the phenomenon of buoyancy-driven fluid motion visible.

Materials: Liter-sized glass container; small, transparent vial (you can make one from a drinking straw: cut to a length of about 8 cm, then close off one end by folding it over and sealing it); thread; food coloring; salt and water.

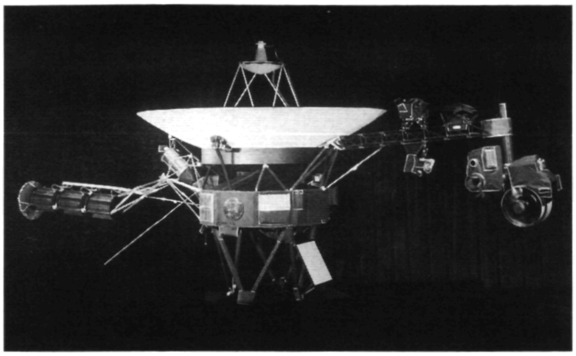
Procedure: (1) Fill the container with very salty water. (2) Fill the vial with unsalted water and add two or three drops of food coloring to it. (3) Attach a thread to the upper end of the vial; lower it carefully, but quickly, into the salt water. Let it rest on the bottom undisturbed. Observe. (4) Repeat the experiment, but with colored salt water in the small vial and unsalted water in the large container. Compare the results.

Discussion: Based on their observations, ask students to determine which solution (salted or unsalted) is denser. Discuss what would happen if there were salt water, or unsalted water, in both the small vial and the larger container. How does this experiment simulate the difficulties of growing crystals in solution? What would happen if the experiment were performed in microgravity?

Further Research: Repeat the experiment with variations. For example, use hot, unsalted water in the small vial; cold unsalted water in the container; vary the amount of salt; use sugar or baking soda instead of salt; try to control the fluid flow by varying both temperature and salt content.

7a Space Exploration

It is human nature to explore, to discover the undiscovered, and to seek to understand the mysterious. Throughout history, explorers have returned to their homelands with wondrous tales of far away lands, inspiring others to follow in their footsteps. They have brought their societies new ideas from other cultures, new goods for trade, and new perspectives. Today, we have explored nearly all of the land mass of the Earth and vast areas of the oceans. However, we have only just begun to explore space.



Voyager, a robotic spacecraft equipped with cameras and other scientific instruments.

Robotic Exploration

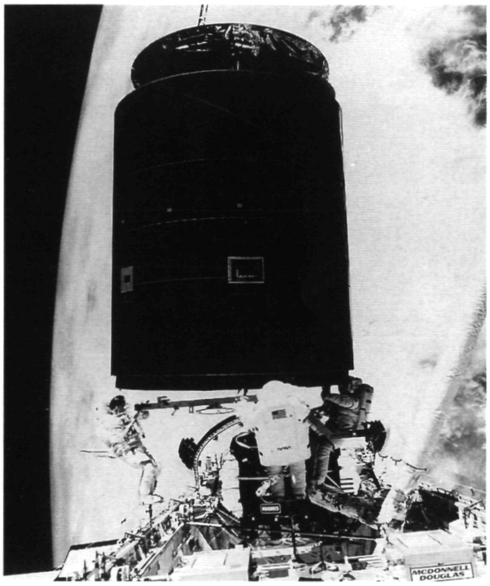
Much of space exploration is carried out by automated, or *robotic,* spacecraft. Robotic exploration complements human exploration, offering advantages in many situations. With no human crews, robotic spacecraft can be small in size, need not employ complex safety features, and can carry out missions extending over many years. Most robotic missions never return to Earth; data is transmitted back to scientists on Earth via radio.

Robotic space probes equipped with cameras and other *remote sensing* instruments have explored every planet in our solar system except Pluto, and have studied the asteroid Gaspra and comet Halley as well. Most of these missions have been *fly-bys,* in which the spacecraft flies past the planet just once before continuing on its journey. The *Voyager 2* mission, for example, flew past Jupiter, Saturn, Uranus, and Neptune between 1979 and 1989. *Orbiters,* spacecraft that repeatedly orbit a world, can carry out longer term studies with far greater detail than fly-bys. Orbiters and *landers,* spacecraft that land on the surface of a world enabling close-up study of surface conditions, have so far reached only the Moon, Venus, and Mars. Spacecraft often perform multiple functions. The *Galileo* spacecraft, which flew by the asteroid Gaspra in 1991, will become an orbiter when it reaches Jupiter in 1995, and will drop a separate probe into Jupiter's atmosphere.

Human Exploration

Human exploration of space is far more complex than robotic exploration due to the inherent difficulties and dangers of space travel. Nevertheless, humans can perform many tasks that would be difficult or impossible to automate. Human ingenuity allows people to react to unexpected situations; for example, astronauts have successfully captured and repaired several satellites in space. Similarly, the Apollo astronauts on the Moon were able to selectively collect geological samples, and future space geologists on Mars are likely to be far more versatile than any machine in identifying scientifically significant phenomena.

The greatest value of human exploration, however, may be in its nurturing of the human spirit and in its ability to capture the global imagination. The first Moon landing (in 1969), for example, was witnessed live on television by some one-quarter to one-half of the world's population at the time. Although humans have not walked on the Moon since 1972, the Moon landings continue to inspire people around the world to reach beyond their perceived limits.

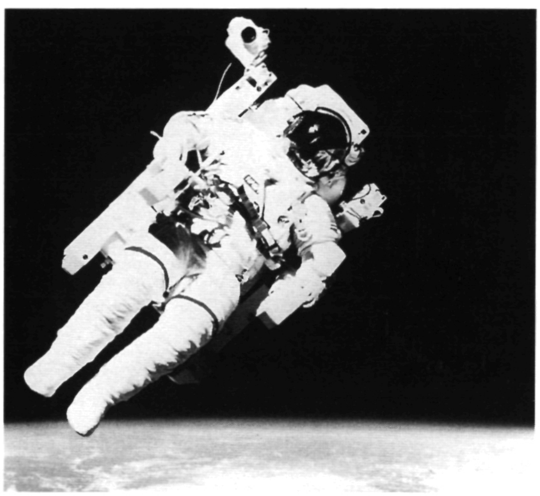


Astronauts repairing a failed satellite while orbiting the Earth at 28,000 km/hr.

Sailors of the Stars

The mid-20th century introduced the world to a new profession: *astronaut* — literally, a "sailor of the stars;" or the Russian term *cosmonaut*—"sailor of the cosmos." Working beyond Earth's atmosphere in an environment with no national boundaries, and looking upon our blue planet with the perspective offered from space, astronauts and cosmonauts have added new dimensions to the human relationship with the Earth and the "heavens."

Like the great explorers of the past, astronauts and cosmonauts take great risks for the cause of exploration. The launching of a rocket is the controlled burning of thousands of tons of explosives. Once in space, the spaceship must provide all life support systems for its occupants; outside, there is no air, and the space environment is bathed in dangerous radiation. The landing, too, has hazards; tremendous heat is generated on the spacecraft as it reenters the atmosphere, and it must slow from an orbital velocity of some 28,000 km/hour to make a soft landing on Earth. It is a testament to the hard work of the thousands of scientists, engineers, technicians, and others who plan and prepare each journey into space that so few have lost their lives in space exploration. Nevertheless, the profession of astronaut or cosmonaut remains one of exploration, with great dangers as well as opportunities for glory.



"Provide ships or sails adapted to the heavenly breezes, and there will be some who will not fear even that void..."

— Johannes Kepler, in a letter to Galileo, 1593.

7b Footsteps on the Moon

Apart from the Sun, the Moon is the brightest and most easily recognizable object in our sky. Throughout history, it has inspired myths, legends, stories, and dreams. The dream of traveling to the Moon is ancient; science fiction stories of travel to the Moon date back nearly 2000 years. In this century, the dream of reaching the Moon has at last been realized.

Between 1969 and 1972 twelve humans walked on the Moon as part of the American Apollo program. It was perhaps the most technologically challenging feat of all time. Someday, the early landing sites on the Moon may be regarded with the same awe that we now regard other great works of large-scale engineering, like the pyramids in Egypt, the great Incan city of Machu Picchu in Peru, the great city of Zimbabwe, the Great Wall of China, or the Cathedral at Beauvais, France. The legacy of Apollo is one of great achievement, symbolizing our technological advancement and our remarkable ability to reach the seemingly unreachable.

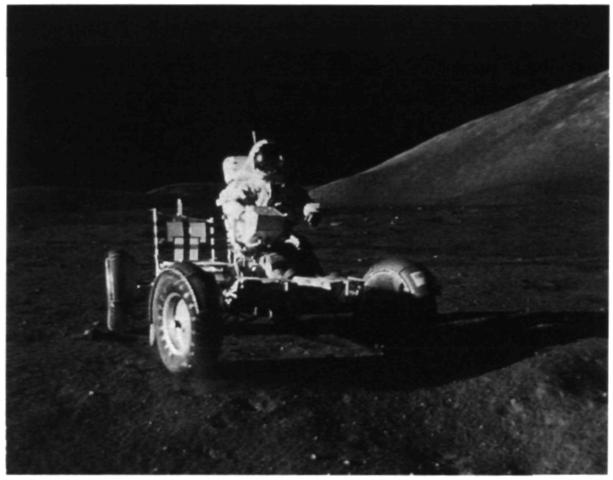
> ***"We came in peace for all mankind."***
>
> — inscription on a plaque left on the Moon by Apollo 11

The Apollo Program

The American program for carrying humans to the Moon was called *Apollo* after the mythological Greek god who carried the Sun across the sky in a chariot. The impetus for Apollo came when President John F. Kennedy challenged the United States to reach the Moon before the end of the 1960s. It was an extraordinary challenge, coming just three weeks after the first space flight by an American—Alan Shepard's 15-minute suborbital flight as part of the *Mercury* program. Six Mercury flights, each carrying a single astronaut, helped us to understand the problems of launching humans into space and returning them safely to Earth. The second American program of human exploration was project *Gemini*. Its 10, two-man missions in 1965 and 1966 studied longer duration space flight, and helped develop spacecraft rendezvous capabilities. Robotic orbiters and landers also helped set the stage for the Apollo landings, surveying the lunar surface and studying lunar soil.

The Soviet Lunar Program

Although the Soviet Union never sent humans to the Moon, they carried out an ambitious program of lunar exploration that included both orbiters and landers. The Soviets achieved the first successful soft landing on the Moon, with their robotic *Luna 9* spacecraft on February 3, 1966. The Soviet *Luna* program continued through 1976, successfully landing 6 more robotic probes on the Moon. Two missions included robotic vehicles, called *Lunokhod,* that travelled many kilometers across the lunar surface. Three missions collected surface samples and returned them to Earth.



Apollos 15, 16 and 17 brought vehicles to help the astronauts explore a larger area around the landing site.

The Apollo missions began tragically when the three astronauts Apollo 1— Virgil I. Grissom, Edward H. White, and Roger B. Chaffee—died in a launch pad fire during a spacecraft systems check on January 27, 1967. Following the Apollo 1 accident, Apollos 2-6 were launched unmanned. Apollos 7-10 carried three astronauts each, testing critical systems for the lunar landing.

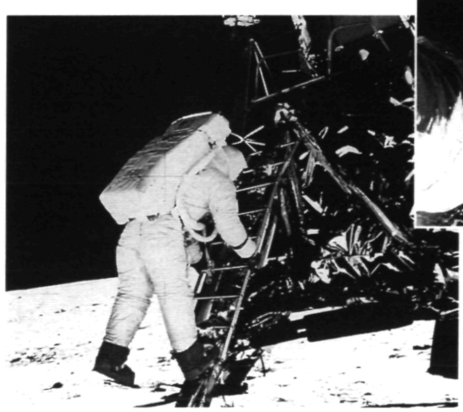
Finally, on July 16, 1969, Apollo 11 was launched to the Moon. Four days later, Neil Armstrong and Edwin Aldrin became the first humans to set foot on another world. The challenge offered by President Kennedy was met.

Six more Apollo missions were sent to the Moon between 1969 and 1972. Apollo missions 12 and 14-17 landed successfully on the Moon. Apollo 13 suffered an accident in space that prevented a moon landing, but averted disaster when its astronauts safely returned to Earth.

Each Apollo mission carried three astronauts. Upon reaching the Moon, one astronaut remained in lunar orbit in the *Command Module,* while two descended to the surface in the *Lunar Module* (LM). Small rockets slowed the LM descent, landing it gently upon the lunar surface. Each pair of LM astronauts spent up to 3 days exploring the Moon. Then, the upper portion of the LM returned to lunar orbit, while the lower portion of the lander remained on the Moon. The two astronauts in the returning LM rendezvoused with the astronaut in the Command Module, and the three returned to Earth together.

> ***"That's one small step for a man, one giant leap for mankind."***
>
> — Neil Armstrong, July 20, 1969

Footprint on moon. With no atmosphere, and therefore no wind or rain erosion, the footprints will remain for thousands of years.



Astronaut descending ladder from lunar module.

7c Continuing Exploration

To the Stars...

As we begin our exploration of the solar system, it is natural to consider travel beyond—to the stars. There, perhaps, we will find other planets, other life-forms, or even other civilizations. Surely, among the hundred billion or more stars in the Milky Way, there are wonders beyond the wildest imaginations.

However, distances to even the nearest stars are nearly a million times the distance to Mars; with present technologies, such voyages would take thousands of years. Even light, travelling at 300,000 km/s, takes years to reach nearby stars and 100,000 years to cross the Galaxy. According to Einstein's theory of relativity, no spaceship could ever exceed the speed of light. Thus, interstellar travel remains a dream for now. Still, a million years ago, humans were small in number and lived only in small regions of our planet. Perhaps, a million years from now, our descendents will look back on us as the generation that first made the leap into space and paved their road to the stars.

We live in a time of great challenges to our civilization as we seek to preserve our planet and to provide peace and prosperity for all. Space exploration, with the new perspectives it provides, helps us to understand and face these challenges. In addition, and perhaps more importantly, space exploration points the way to a future. Humans in low-Earth orbit are now commonplace, working in the American Space Shuttle or the Russian space station *Mir* (Russian for "peace"). Someday, human presence may be equally common on the Moon, Mars, or beyond.

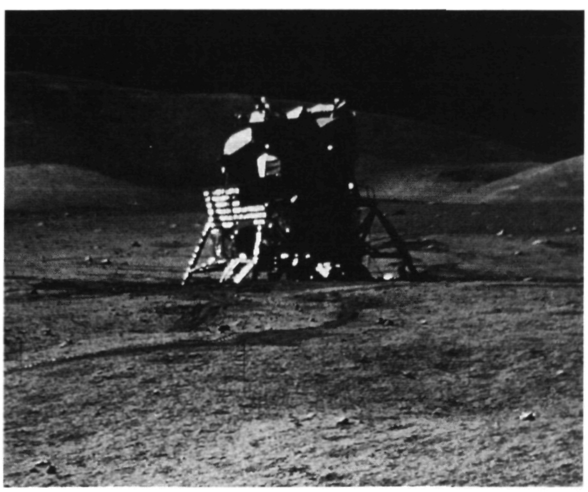
Space Stations

Space stations are used primarily to study the effects of the space environment on materials, physical and biological processes, human physiology, and human behavior. The first space station, the Soviet *Salyut 1,* was launched in April 1971. The Soviets launched and used a total of seven *Salyut* space stations through the early 1980s. More recently, the Russian space station *Mir* has housed cosmonauts since its launch in 1986. The first American space station, *Skylab,* housed three crews of three astronauts during 1973 and 1974. A larger and more complex space station, *Freedom,* is under development as a joint effort among the United States, the European Space Agency, and Japan.

Skylab, the first American space station.

The Moon

Even beyond its appeal to our spirit of exploration, there are many practical reasons for returning to the Moon. Lunar geology could provide insights into the formation and history of our solar system. The Moon, with its geologically stable, low-gravity surface, and lacking atmosphere to absorb starlight, is an ideal location for astronomical observatories. The Moon is rich in certain minerals, and some scientists believe that lunar mining and manufacturing could provide valuable commercial products for people on Earth. Moreover, because its relatively low *escape velocity* makes it far easier to launch spacecraft or materials from the Moon than from the Earth, the Moon might someday become the primary starting point for other interplanetary missions.



The last picture of the Apollo spacecraft on the Moon, Apollo 17, December 1972. When will we return?

Nevertheless, the Moon is a harsh and desolate place. Humans working on the Moon for extended periods of time will likely have to live underground to be protected from radiation and meteorite impacts, and to be insulated against the extreme temperature changes between the two-week lunar days and nights. Sources of food, air, and water will have to be developed from lunar resources or brought from Earth. The long-term effects on human physiology of working in the Moon's low gravity, about one-sixth that of Earth's, are not yet known.

Mars and the Solar System

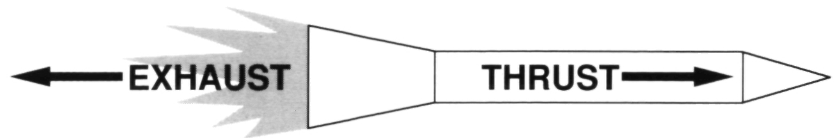
Travel to Mars or to other planets is far more difficult than travel to the Moon. The distances are much greater, necessitating longer journeys. The trip to Mars, for example, would require at least several months in each direction with present propulsion technologies. We still have much to learn about the effects of the space environment on humans before sending people to the planets. In the meantime, international missions of robotic exploration may help lead the way for human presence.

Sunset on Mars, photographed by the Viking 1 lander. Someday, perhaps, humans will witness this vista.

Mars is the most attractive planet for human exploration. Although humans could not survive outside of spacesuits or pressurized habitats on Mars, it is still the most Earth-like planet. The thin Martian atmosphere moderates the temperatures; Martian gravity, about half that of Earth, should be relatively comfortable; the Martian day, just over 24 hours, would be familiar; and water, while not present in liquid form, can be found in Martian rocks and in the polar ice caps of Mars. Once human outposts are established on Mars, exploration of other worlds in our solar system is bound to follow.

7d For the Classroom

Rocket Propulsion



Activity 1:
A Balloon Rocket

Background: Rockets are used to go into space and to maneuver spacecraft in space. Rockets operate in accordance with *Newton's third law of motion:*

For every force of action, there is an equal and opposite force of reaction.

A rocket is designed to force gas out its back end; as a result, an equal and opposite force pushes the rocket forward. Equivalently, we can say that the force of the *exhaust* out of the rocket creates a reactive force of *thrust* to propel the rocket forward. A common misconception holds that rockets must push against something (e.g., the ground, or air); in fact, the rocket is propelled simply by its own thrust. Thus, rockets can be launched in space, from Earth orbit toward another planet. Also, small rocket thrusters can be used to make subtle adjustments to a spacecraft's orbit or to turn the spacecraft in any direction.

Modern rockets work through the combustion of liquid or solid fuels, creating a hot gas. By ensuring that the gas can escape only through a narrow *nozzle,* the direction of the exhaust, and hence of the opposite thrust, is controlled. In this activity, we use an inflated balloon with an open neck as a simple rocket. Instead of a hot gas produced by combustion, the balloon exhaust is created by escaping air from the collapsing balloon.

Materials: Balloon, preferably cylindrical shape; long piece of thread or fishing line; drinking straw; tape.

Procedure:

1. Inflate the balloon without sealing the neck, then release the balloon in the classroom. The balloon will fly off, but not in a straight line; instead, it will seem to fly erratically. Ask the class to explain how the balloon is like a rocket, and why its flight is erratic. (Answer: the rubber neck of the balloon, because it is not rigid, does not hold steady as the air escapes. At every moment, the balloon is thrust forward in a direction opposite to its exhaust—the escaping air. Because the exhaust changes direction as the rubber neck moves about, the balloon changes direction as well.)

2. Next, try to get better control of the balloon rocket by making it fly along a taut piece of thread or fishing line; the thread acts as a simple *guidance system.* Make sure the thread is long enough to stretch across the room. (i) Put the thread through the straw; have students hold both ends of the thread taut, or tape them securely to the wall. (ii) Inflate the balloon, and clamp its neck with fingers or a clothing pin. Tape the balloon to the straw. (iii) When ready, release the neck to let air escape from the balloon. The balloon should propel the straw forward along the thread. (iv) Repeat the experiment several times. Discuss the results. Does it work equally well every time? How could the balloon be better controlled?

3. (Optional) Ask the class to consider ways of better controlling the balloon in its flight along the thread. Break them into small teams, each with its own thread stretched across the room, and its own balloons. Give them time to invent methods for better controlling the balloon flight. After they've had time to do their balloon *engineering,* let all of the groups have a balloon race, releasing their balloon rockets simultaneously along the threads.

4. (Optional) For an even greater engineering challenge, ask your students to devise a method so that the balloon will fly relatively straight even without using the thread for guidance. Again, you could create a contest to see who can build a balloon rocket that can fly reliably, time after time, all the way across the classroom. If you give them enough time, or assign it as homework or a longer term project, you may find some fairly sophisticated engineering designs for balloon rockets.

Activity 2:
The University of the Moon

Imagine that, in the not too distant future, an international university is established on the Moon. Ask your students to try some of the following:

1. Describe, with pictures, models, or an essay, the University of the Moon. What does it look like? How is it protected against the harsh outside environment? Where does it get its air, food, and water? How many students study there, and how many other people live or work there?

2. Make a catalog listing courses offered by the University of the Moon. Write a short course description for each, explaining the unique reasons for offering the course on the Moon. (Be sure that you don't limit yourself to considering only science courses.)

3. You have decided to apply to study at the University of the Moon. As part of your application, write an essay explaining what you hope to learn on the Moon, and how you hope to use your experience at University of the Moon for the benefit of humanity upon your return to Earth.

4. You've been accepted to attend a special, one-year study program at the University of the Moon. Discuss your preparations. What kinds of equipment and supplies will you need to survive on the Moon? Make a "packing list" for your trip.

5. One day, your class takes a field trip to the Apollo 11 landing site. Write a letter home, describing the field trip and your thoughts on seeing the place where humans first set foot on another world.

6. In the Moon's low gravity, about one-sixth of the Earth's, everything will weigh about one-sixth as much as it would on Earth, including you. You will be able to jump higher, throw a ball farther, and so on. Describe your recreation on the Moon. If you wish, invent a new sport to be played on the Moon.

7. Design a t-shirt and a logo for the University of the Moon.

8. Ask some students to play the role of interviewers for local television and conduct an interview of students who have just returned from a year at the University.

8a Entering the Space Age

From early rocket experiments in many nations, we now have national and international space programs. The space age is a global age, and it has been characterized by both conflict and cooperation.

Rocketry

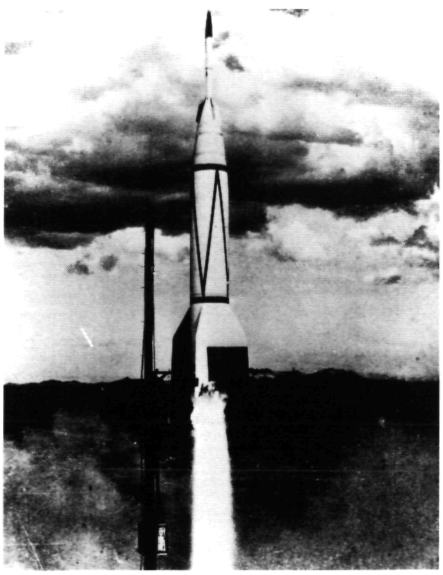
The earliest rockets were developed in China about a thousand years ago. Until the 20th century, however, rockets were used around the world only for fireworks displays and military purposes. It was a small-town school teacher in Russia, Konstantin Tsiolkovsky, who developed the theories and concepts of modern space travel. He developed physical principles of space flight, and the concepts for liquid-fueled rockets. He also wrote science fiction and advanced the idea that international cooperation would be a necessity in space exploration.

Tsiolkovsky's writings formed the basis for work by other pioneers of rocketry, like Robert Goddard of the United States, Hermann Oberth of Germany, and Robert Esnault-Pelterie in France. These and other people made great progress in the development of launch and flight systems. By the beginning of World War II, astronautical societies dedicated to the development of rocketry were springing up around the world. Although each national group worked independently, they built upon each other's efforts.

Competition in Rocketry

Although the early rocket pioneers were inspired by dreams of journeys to the Moon and Mars, much of the history of rocketry was driven by military considerations. German scientists, led by Wernher von Braun, developed the *V2 rocket* as a weapon during World War II; it became the basis for later rocket development. After the war, many of the German scientists joined either the American or Soviet rocket programs; von Braun came to the United States. Both nations began dual rocketry programs, with one component developing ballistic missiles for military use, and the other developing rockets to reach space. The *space race* was on.

Robert Goddard, rocket pioneer.



V-2/WAC/Corporal lifts off from White Sands Proving Ground, New Mexico, 1949.

The Space Race

Both the United States and the Soviet Union began vigorous space programs during the 1950s. The space race soon became a visible symbol of the *Cold War*, characterized by intense competition between the two superpowers. Both nations devoted substantial effort and resources to their space programs, in the belief that success in space would demonstrate the superiority of one nation over the other.

On October 4, 1957, the Soviets succeeded in launching the first artificial satellite into space, *Sputnik 1*. The Americans attempted to follow with a satellite called *Vanguard* on December 5, 1957. In contrast to the Soviets, who had offered pictures only after their launch, the American attempt was witnessed live by the world press. To American embarrassment, the rocket exploded on the launch pad. But American success followed soon thereafter, with the launch of the *Explorer 1* satellite on January 31, 1958.

Despite their cold war origins, both Sputnik 1 and Explorer 1 provided important scientific data and served no direct military purpose.

The Soviet Union also took the early lead in human space exploration. It successfully launched the first man into space, Yuri Gagarin, on April 12, 1961. Gagarin orbited the Earth once before landing safely on the ground. The Americans began human exploration with a suborbital flight by Alan Shepard on May 5, 1961; the first American to orbit the Earth was John Glenn, on February 20, 1962. The Soviets also launched the first woman into space, Valentina Tereshkova, on June 16, 1963.

Toward Cooperation

As early as the 1950s, there were signs of a developing trend toward international cooperation in space exploration. The U.S. developed cooperative space ventures with Europe, Canada, and Japan, while the Soviet Union pursued cooperation with its allies in Eastern Europe and Asia. Other nations, too, began to demand access to the benefits of space, and the United Nations developed guidelines for cooperation in space. By the mid-1970s, even the superpower rivals were cooperating, as demonstrated when American astronauts and Soviet cosmonauts linked up in space for the *Apollo-Soyuz Test Project* in 1975. Today, encouraged by the mutual benefits of sharing costs and capabilities, international scientific and technological cooperation in the exploration of space is commonplace and growing.

American and Soviet space explorers met in Earth orbit in 1975 as part of the Apollo-Soyuz project.

8b Global Cooperation

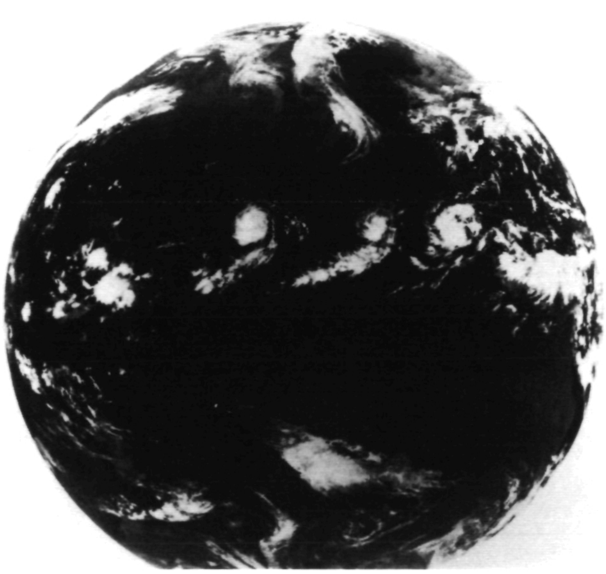
International cooperation in space offers significant benefits. The pooling of resources allows nations to share the costs of complex, large-scale programs. Further, in the complex era of the space age, different nations have developed different sets of expertise; cooperation provides broad access to this expertise. Perhaps most importantly, space cooperation strengthens ties between nations and serves as a visible symbol of good relations.

Meteorology, Telecommunications, and Navigation

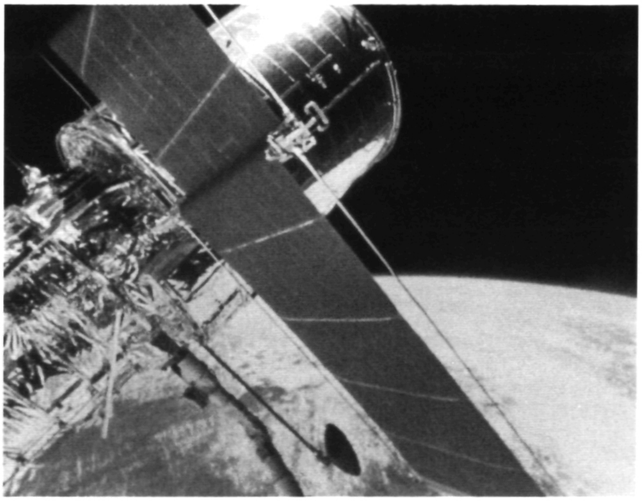
Perhaps the greatest direct human impact from the space program has been in the areas of meteorology and telecommunications. Today, pictures and data from satellites are critical to weather prediction in every country of the world. Because of these satellites, storms can be tracked and people warned of impending meteorological disasters.

In the area of telecommunications, satellites have brought the world much closer together. Striking and powerful television images are now likely to be seen virtually instantaneously around the world. Telecommunications satellites often are built and operated by international consortia; anyone on Earth can receive transmissions by using an appropriate antenna.

Navigation satellites provide another practical benefit of space to people of every nation. Ships and airplanes now routinely use satellites to accurately note their locations on Earth. As navigational capabilities improve, collisions become less likely, and routes can be charted more efficiently.



Satellites provide data on weather for the entire planet. (National Oceanic and Atmospheric Administration)



NASA's Hubble Space Telescope, built as a cooperative effort with the European Space Agency, provides astronomical data to scientists worldwide.

Scientific Cooperation

Space science activities have a long history of international cooperation. Missions are often built and operated by multinational groups, and scientific data often are made available to scientists from any nation. There are many examples of cooperation in space science. The Soviet *Vega* mission to Halley's comet in 1986 carried American-built instruments. The European Space Agency contributed a specialized camera and solar panels for the *Hubble Space Telescope.* The Federal Republic of Germany developed the propulsion system for the *Galileo* mission to Jupiter. The European *Ulysses* spacecraft, designed to observe the poles of the Sun, included contributions from the United States and was launched by the Space Shuttle in 1990. Two series of missions, the *International Microgravity Laboratory* (IML) and the *Atmospheric Laboratory for Applications in Science* (ATLAS), include scientists and experiments from the United States, Europe, Japan, and Canada. And nearly all Russian missions today are cooperative efforts with other nations. In addition, tracking stations that help maintain contact with space probes are located around the globe.

Scientists from virtually every nation cooperate in research related to space science. For example, data are needed from around the world to supplement remote sensing data collected by satellites for studies of the global ecology. Suborbital scientific campaigns using high-altitude aircraft, balloons, and sounding rockets take place every year in locations around the world. The combination of these efforts leads to a vast, interconnected system of space exploration intended to provide the greatest scientific benefit to the greatest number of people.

The American Space Shuttle often carries international crews. Here, we see the crew of the Spacelab I (STS-9), with astronauts from both the United States and Germany, November, 1983.

Human Spaceflight

While only the United States and Russia have launched humans into space, astronauts from dozens of countries have orbited the Earth in cooperative ventures with the Americans or Russians. Even major space systems have elements of cooperation. For example, the *Remote Manipulator System* on the Space Shuttle, used to deploy and capture satellites, was constructed by Canada.

The future of human space exploration is almost surely international. Space Station Freedom, a project led by the United States, is being developed with major contributions from Canada, Japan and the nations of the European Space Agency. For the more distant future, many nations are discussing possible collaborations in human missions to the Moon or Mars.

8c International Space Year

The International Space Year (ISY) in 1992 celebrates the global spirit of the space age. It coincides with the 35th anniversary of the International Geophysical Year, a global scientific effort that led to increased cooperation in research and ushered in the space age. It also marks the 500th anniversary of the first voyage of Columbus to the Americas.

ISY does not end at the end of 1992. Rather, it is meant to be only the beginning of a long-term effort dedicated to global cooperation, discovery, exploration, and education. Hundreds of projects will begin around the world for ISY and will continue long after. As long as humans work together to explore the universe, the spirit of ISY will live on.

The Outer Space Treaty

Concerned about whether space would be used for cooperation or conflict, the United Nations developed a treaty on the use of space. On October 10, 1967, the "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies" entered into force. Among its provisions, it notes that the exploration of space is the province of all humanity, and it calls for freedom of scientific investigation and encourages international cooperation in space research.

"We came in peace for all mankind."

Space Agencies and ISY

Today there are dozens of national and international agencies with space activities. The largest are in the United States, Russia, Japan, China, and the consortium of nations that make up the European Space Agency (ESA).

To support ISY, agencies from around the world came together to create the Space Agency Forum on International Space Year (SAFISY). Established in 1988, SAFISY currently has 29 members (space agencies and ministries responsible for space) and 10 affiliates (other international organizations with a role in space activities). SAFISY sponsors projects ranging from specialized research symposia to broad educational programs.

The Antarctic Precedent

U.S. exploration of Antarctica dates back to the 1800s, with a number of large-scale expeditions mounted during 1928-1930 and again in 1933-1935. Antarctic exploration gained an added impetus during the International Geophysical Year (IGY) that was celebrated from July 1, 1957, to December 31, 1958. Within a few years after the IGY, 12 nations had established some 60 research stations in Antarctica.

Scientists, support personnel, and visitors pose at the South Pole, March 1985. (National Science Foundation)

In May 1958, U.S. President Eisenhower invited the 11 other Antarctic IGY nations to come to Washington to draft an Antarctic Treaty. Referring to the spirit of international cooperation developed during IGY, Eisenhower wrote: "Our proposal is directed at ensuring that this same kind of cooperation for the benefit of all mankind shall be perpetuated."

The resulting treaty is a remarkable achievement that established Antarctica as a special zone, recognizing no territorial claims. It provides that Antarctica be used for peaceful purposes only; prohibiting military operations except in support of peaceful activities. It emphasizes scientific investigation and encourages cooperation through the exchange of program plans, personnel, observations and results. The Antarctic treaty is a model of international cooperation that can be applied in similar ways to space exploration.

ISY

Nations represented in SAFISY include: Argentina, Australia, Austria, Belgium, Brazil, Canada, China, Denmark, Germany, Finland, France, India, Israel, Italy, Japan, Netherlands, Norway, Pakistan, Russia, Spain, Sweden, Switzerland, Thailand, the United Kingdom, and the United States.

For the Classroom

Celebration of ISY

The 1992 International Space Year (ISY) is only the beginning of a global celebration of our achievements and our future aspirations in space. Get your students involved in the ongoing celebration of space. The following lists a few suggestions for student projects; encourage your students to come up with additional activities. For greater impact, organize a school "ISY fair" to showcase the student projects; invite parents and friends to attend and to learn about international efforts in space. Activities can be adapted to the grade level of your students. Elementary school students will enjoy the activities while they learn. High school students can develop very sophisticated activities, demonstrations, and performances that might draw attention throughout your community.

Invitations, Program, and Banner: A school fair in celebration of ISY requires preparation. A small group of students should act as an organizing committee to: (1) Design, print, and distribute invitations to parents and friends. (2) Coordinate all of the ISY fair events into an organized program; students might wish to make a program book listing all of the events. (3) Create a large banner to hang over the ISY fair entrance.

Poster Set Activities: If your class has worked through other activities suggested in this poster set, then you already have a lot to show at the fair. Ask students to turn their completed activities into a format suitable for display or demonstration to parents and friends.

Essays: Develop a collection of essays from your students to put on display at the ISY fair. Some suggested topics: the perspectives we develop from space; humanity's future in space; the benefits of space exploration; the history of human exploration; international cooperation in space or on a particular space mission; etc. In many cases, essays will require students to do some independent research to gain the necessary background.

Poetry: Ask your students to write poems about perspectives from space, or about other aspects of space. Encourage them to be creative: some poems can highlight serious, philosophical issues, while others might be light-hearted rhymes. Poetry can be read aloud at the ISY fair.

Music: The popularity of music makes it an ideal vehicle for getting students interested in space. Some students might write traditional music or folk songs, while others might write rap or other modern musical forms. If you have any real composers in your class, let them try to write a purely instrumental piece that evokes thoughts about space. Perform the songs at the ISY fair.

Dance: Translating a concept like *Perspectives from Space* into a form of dance is challenging, but not impossible. For inspiration have students view tapes of space missions or their development. Ask interested students to develop a dance performance to celebrate ISY.

Drama: Developing a dramatic presentation about space can involve most or all of your class. As with all of the activities described here, encourage your students to look for creative ideas. Dramatic presentations might range from simple reenactments of lunar landings to multi-act plays set on another planet.

Painting and Sculpture: Paintings and sculptures can capture unique aspects of space. NASA, for example, has a long tradition of commissioning artists to create paintings and sculptures for the space program. Ask students to attempt to capture the spirit of International Space Year with a painting or sculpture.

Science Demonstrations: Set-up a selection of simple science demonstrations. Besides the science activities elsewhere in this poster set, you can find activities from many other sources. For each demonstration, be sure to explain how the science is connected to space programs.

Mars Base: Ask students to design the first permanent human base on Mars, to showcase at the ISY fair. Any or all of the following might be included as part of this activity:

1. The voyage to Mars is long and complex. Design a transportation system for taking people from Earth to Mars. The system might include just a single, powerful rocket, or it might be much more complex. For example, it might involve several types of vehicles, stopovers at space stations or Moon bases, stopovers at Phobos or Deimos (moons of Mars), etc. Unless your students design a system with very futuristic technologies, the trip to Mars will take several months. Be sure that the necessities of such a long voyage are designed into their spacecraft.

2. Design the layout of the Mars base. Be sure to remember that, while there is a thin atmosphere on Mars, humans could not survive in it without pressurized spacesuits and air tanks. Location of the base will be very important. Water might be more readily available near the polar caps for example, but temperatures would be colder and the base would be immersed in darkness during the long Martian winter. Consult maps of Mars, which can be found in many books about the planets.

3. Describe, with words, drawings, or models, the ecology of the Mars base. Because of the long voyage from Earth, the base will need to be self-sufficient for food, air, and water.

4. The surface of Mars has roughly as much area as all of the continents (but not the oceans) on Earth, put together. The first base will be small and isolated. Develop a system for exploring Mars.

5. Since the base will be remote and self-sufficient, it will need laws. Write a "constitution" for the Mars base. Don't forget that special laws will be needed to ensure survival. Consider, for example; the severely limited resources of food, air, and water; the danger of punctures or explosions to the pressurized base; the difficulties of travel or rescue outside the base; etc.

Also, the base will be very international in nature. What languages will be spoken? If a disagreement erupts between nations on Earth, how will it affect the citizens from those countries living on Mars? Will their primary allegiance be to their countries on Earth, or to Mars? (Students may be tempted to give the Mars base a great deal of autonomy. Remember, however, that the base will be dependent on the Earth because it needs critical resources, and because its personnel may wish to return to Earth. If their laws are too antagonistic toward Earth, they might find their futures in jeopardy.)

NASA Education

For more information on NASA education programs for the classroom, teachers may contact the following:

Teacher Resource Center Network

Teacher Resource Centers (TRCs) contain a wealth of information for educators: publications, reference books, slides, audio cassettes, video cassettes, telelecture programs, computer programs, lesson plans and activities, and lists of publications available from government and non governmental sources. Because each NASA Field Center has its own areas of expertise, no two TRCs are exactly alike. Phone calls are welcome if you are unable to visit the TRC that serves your geographic area.

To offer more educators access to NASA educational materials, NASA has formed partnerships with universities, museums, and other educational institutions to serve as Regional Teacher Resource Centers (RTRCs). For the location of the RTRC nearest you, please contact the TRC serving your geographic region. (See below)

NASA CORE

CORE is a center established for the national and international distribution of NASA produced educational materials in audiovisual format. Educators can obtain a catalogue of these materials and an order form by written request, on school letterhead to:

NASA CORE
Lorain County Joint Educational School
15181 Route 58 South
Oberlin, OH 44074
Phone: (216) 774-1051, Ext. 293 or 294

NASA Spacelink

Spacelink is a computer information service that educators can access for news about current NASA programs, classroom activities, lesson plans, and publications.

Users can access Spacelink with a computer and modem by calling (202) 595-0028 or through the Internet at the following address:

spacelink.msfc.nasa.gov
xsl.msfc.nasa.gov
192.149.89.61

NASA Select Television

NASA Select television offers live mission coverage and educational programming on space and related topics. Programs cover topics such as biology, geology, the atmospheric and Earth sciences, mathematics, and engineering concepts.

Programming starts at noon Eastern time, Monday through Friday, and is shown in four-hour blocks (repeated at 4 p.m., 8 p.m., and midnight). The 2 p.m. (and 6 p.m., 10 p.m., and 2 a.m.) program is specifically designed and targeted for classroom use. All programs may be taped for use at a later time.

NASA Select is available through local cable and is transmitted by satellite dish. For more information contact:

NASA Select
c/o Associate Administrator for Public Affairs
NASA Headquarters/Code P
Washington, DC 20546
Phone: (202) 554-6401

Teacher Resource Centers

NASA Teacher Resource Center
Mail Stop TO-25
NASA Ames Research Center
Moffett Field, CA 94035
PHONE: (415) 604-3574

NASA Teacher Resource Center
Mail Code 130.3
NASA Goddard Space Flight Center
Greenbelt, MD 20771
PHONE: (301) 286-8570

NASA Teacher Resource Center
Mail Code AP-4
NASA Johnson Space Center
Houston, TX 77058
PHONE: (713) 483-8696

NASA Educators Resource Laboratory
Mail Code ERL
NASA Kennedy Space Center
Kennedy Space Center, FL 32899
PHONE: (407) 867-4090

NASA Teacher Resource Center
Mail Stop 146
NASA Langley Research Center
Hampton, VA 23681-0001
PHONE: (804) 864-3293

NASA Teacher Resource Center
Mail Stop 8-1
NASA Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135
PHONE: (216) 433-2017

NASA Teacher Resource Center
Alabama Space and Rocket Center
Huntsville, AL 35807
PHONE: (205) 544-5812

NASA Teacher Resource Center
Building 1200
NASA John C. Stennis Space Center
Stennis Space Center, MS 39529
PHONE: (601) 688-3338

NASA Teacher Resource Center
JPL Educational Outreach
Mail Stop CS-530
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
PHONE: (818) 354-6916

NASA Dryden Flight Research Facility
Public Affairs Office (Trl. 42)
NASA Teacher Resource Center
Edwards, CA 93523
PHONE: (805) 258-3456

Wallops Flight Facility
Education Complex - Visitor Center
Building J-17
Wallops Island, VA 23337
PHONE: (804) 824-1176

National Aeronautics and
Space Administration

NASA Headquarters
Washington, DC 20546